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USER'S MANUAL EXTERNAL BURNING PROPULSION ANALYSIS (EBPA)

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April 1981

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Prepared for

AIR FORCE ROCKET PROPULSION LABORATORY
Director of Science and Technology
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Edwards AFB, CA 93523

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This user's manual provides instructions to initiate, run, and terminate the External Burning Propulsion Analysis (EBPA) computer program. Details are given of inputs, processing flow, instructions for use, outputs (including loadsheets for sample case), operating messages, troubleshooting, and requisite hardware and support software. The program was developed for operation on the CDC 6400/7600 and CYBER 174 computing systems, but its machine dependency has been

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20 ABSTRACT (continued)

minimized. The EBPA program is self-contained and requires no communication with outside programs. In addition to the program tape, a single chemistry data tape is required for its operation.

CONTENTS

List of Figures

List of Tables

NOMENCLATURE

A_1	Thruster nozzle throat area
A_{OB}	Total area of base bleed apertures
C_B	Outer flow expansion angle fraction
C_{crit}	Gaussian distribution fuel percentage
E_{ratio}	Nozzle area exit to throat ratio
I_{cg}	Vehicle center of gravity
KINDF	Selected type of fuel
KINDO	Selected type of oxidizer
LC	Local or freestream conditions flag
M_L	Local Mach number
$\dot{m}_B$	Base bleed flow rate
M_∞	Freestream Mach number
N_{nozz}	Number of nozzles around base periphery
N_z	Number of mixing zones
O/F	Injectant oxidizer to fuel ratio
P_{B_1}	Base pressure
P_{B_2}	Pressure at critical point
PCT_R	Upstream correlation weight
PF_A	FRJI subprogram print flag
PF_B	FRJI subprogram chemistry print flag
PF_P	BBMODL subprogram print flag
PHI	Roll angle or wind angle
P_j	Thruster chamber pressure
P_L	Local pressure
P_N	Pressure at reattachment

NOMENCLATURE (continued)

P_∞	Freestream pressure
$\emptyset_B$	Annulus streamline divergence angle of base plane
R_N	Vehicle nose radius
R_{w_f}	Inner flow radius to base plane radius ratio
T_L	Local temperature
T_∞	Freestream temperature
V_B	Bleed flow velocity
V_L	Local velocity
V_M	Inner shear layer velocity profile correlation
X_{body}	Overall vehicle length
X_{cone}	Vehicle forebody length
X_{jet}	Thruster site distance from vehicle base
α	Angle of attack
α_1	Forward inclination of jet
β	Nozzle exit cone half-angle
γ	Specific heat ratio of air
ΔP_B	Bleed flow pressure drop
δ_{Δ_1}	Annulus 1 divergence angle increment
δ_{Δ_2}	Annulus 2 divergence angle increment
δ_{f_1}	Annulus 1 divergence angle final table entry
δ_{f_2}	Annulus 2 divergence angle final table entry
δ_{0_1}	Annulus 1 divergence angle initial value
δ_{0_2}	Annulus 2 divergence angle initial value

NOMENCLATURE (continued)

δ_R	Annulus 2 inner boundary radius increment
δ_1	Annulus 1 divergence angle computation
δ_2	Annulus 2 divergence angle computation
ε_g	Inner flow half-angle error criteria
ε_s	System performance error criteria
η_R	Equilibrium flow fraction
σ_B	Annulus streamline divergence angle at base plane
θ_j	Angular location of thruster
$\theta_{w_{\Delta_1}}$	Annulus 1 cavity half-angle increment
$\theta_{w_{\Delta_2}}$	Reserved
$\theta_{w_{f_1}}$	Annulus 1 cavity half-angle final table entry
$\theta_{w_{f_2}}$	Reserved
$\theta_{w_{0_1}}$	Annulus 1 cavity half-angle initial value
$\theta_{w_{0_2}}$	Annulus 2 inner flow half-angle initial value
θ_{w_1}	Annulus 1 cavity half-angle computation
θ_{w_2}	Annulus 2 inner flow half-angle computation
θ_1	Cone half-angle
θ_2	Body half-angle

Section 1

INTRODUCTION

This user's manual provides instructions to initiate, run, and terminate the External Burning Propulsion Analysis (EBPA) computer program. This program was developed by the McDonnell Douglas Astronautics Company under sponsorship of the Air Force Rocket Propulsion Laboratory, Edwards Air Force Base, California. The program was developed for operation on the CDC 6400/7600 and CYBER 174 computing systems, but its machine dependency has been minimized. The EBPA program is self-contained and requires no communication with outside programs. In addition to the program tape, a single chemistry data tape is required for its operation.

Section 2

INPUTS

The EBPA program is essentially composed of two computational modules: a Fuel Rich Jet Interaction (FRJI) subprogram and the Base Burning Modeling (BBMODL) subprogram. The input data for the EBPA program will be described, first for those inputs required to execute the FRJI portion of the program, which will define the flow field at the base plane, and second, for the inputs exclusively required for the injectant annulus surrounding the base cavity.

2.1 FRJI Subprogram Input

The input data for the FRJI subprogram consists of vehicle parameters, flight parameters, injector parameters, chemistry parameters, local conditions, and option flags. An example of the loadsheet is shown in Figure 1. The input glossary is provided in Table 1 which gives the name, symbol, location, and definition of each input variable.

Figure 2 shows a schematic of the biconic vehicle configuration. From the schematic, the usage of θ_1, θ_2, X_{body}, X_{cone}, I_{cg}, and Z_{jet} is straightforward. Since a conic vehicle is a special case of a biconic vehicle, $\theta_1 = \theta_2$ for a conical vehicle. A boattailed vehicle can be approximated by setting $\theta_2 < 0$.

Flight parameters must be input when the local conditions at the injector are to be calculated by the computer program. When inputting free-stream conditions M_∞, T_∞, P_∞, the local condition flag LC in location 068 must be set to 1.0 for the local flow subroutine to make the injector computations. The program defaults to LC = 1.0. When the free-stream conditions (M_∞, T_∞, and P_∞) are input, the vehicle angle of attack α and roll angle ϕ must also be input. It is recommended here that zero be used for both values. The sign convention on α and ϕ is such that when looking forward with a base view of the vehicle a wind direction from a counterclockwise direction is positive. With the injector located on top ($\theta_j = 0$), a positive α will put the injector on the windward ray, and a negative α with $\theta_j = 0$ will put the injector on the leeward ray.

EXTERNAL BURNING PROPULSION ANALYSIS

LOADSHEET 1

MUST BE FILLED IN FOR PROPER PROCESSING

63	65 66	67 68	70 71 72
6D	RR	CASE	PART CASE

JOB TITLE CARD

E KEYPUNCH: PUNCH IN ALL CARDS

QUAN	LOC	VALUE	
VEHICLE PARAMETERS			
θ_1	1		DEG
θ_2	2		DEG
X_{body}	3		FT
X_{cone}	4		FT
D_{NI}	30		
θ_j	65		DEG
R_E	66		FT
R_N	67		FT
FLIGHT PARAMETERS			
M_∞	5		
ALT	6		FT
P_∞	7		PSF
T_∞	8		°R
α	9		DEG
PHI	10		DEG
I_{CG}	11		FT
γ	12		
INJECTOR PARAMETERS			
P_j	13		PSI
A_j	14		IN^2
E_{RATIO}	15		
α_j	16		DEG
Z_{JET}	17		IN
β	18		DEG

QUAN	LOC	VALUE	
CHEMISTRY PARAMETERS			
KINDF	19		
KINDO	20		
η_R	21		
C_{crit}	29		
N_Z	32		
O/F	64		
LOCAL CONDITIONS			
M_L	24		
P_L	25		PSF
T_L	26		°R
V_L	27		FT/SEC
OPTION FLAGS			
PF_A	39		
PF_3	40		
P_C	50		
LC	68		

Figure 1 EBPA Sample Loadsheet 1

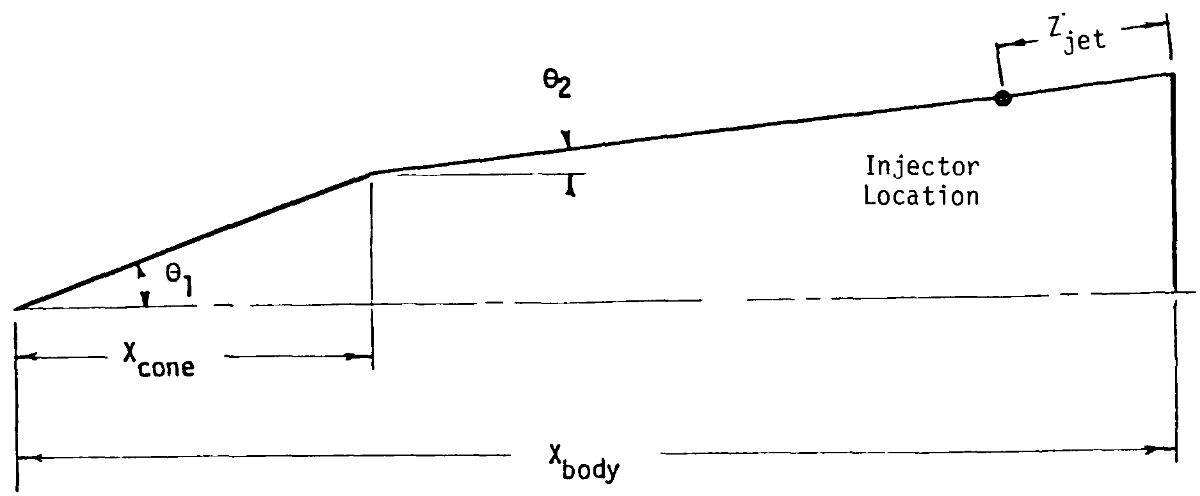

Figure 2 Vehicle Configuration and Nomenclature

If the local conditions on the vehicle are known, it is not necessary to input M_∞, T_∞, P_∞, α, or ϕ. Instead, the local conditions P_L, T_L, and M_L are input, and flag LC set equal to 0.0. It is not necessary to input V_L as this is always calculated internally. Note that in either type input (free stream or local), the specific heat ratio for air γ must always be input.

The type of fuel KINDF and type of oxidizer KINDO in the chemistry parameters can be selected from the list of fuels in data block FRJIB, as shown in the Appendix. The parameters ETAR and CCRIT are determined from experimental data. The number of zones N_Z can vary from 1 to 10, but 3 are generally sufficient. The oxidizer to fuel ratio O/F is the fractional ratio of oxidizer to fuel. In the event that the fuel type already contains the oxidizer as in some solid propellants, input the same fuel type number for both KINDF and KINDO and set O/F equal to 1.0.

The option flags consist of two print flags PF_A and PF_B, and the local condition flag LC. All are given in the input glossary in Table 1.

2.2 BBMODL Subprogram Inputs

These inputs consist of geometry parameters, annulus configuration control variables, and base bleed parameters. An example of the loadsheet is shown in Figure 3. The input glossary is included in Table 1.

Geometry inputs include the number of jet nozzles around the vehicle periphery, streamline divergence angle at the base, mixing angle, and inner flow to base plane radius ratio. Annulus configurations are determined by divergence streamline angles downstream of the base, cavity wake half angle and inner flow half angle. These inputs are used to indicate if system performance is to be determined or to provide results from tabulated values of the angular measurements. The table option can be used to make estimates of the region of convergence of base pressures. The print flag PF_P should be 1. or 2. if the table option is exercised. Base bleed inputs include flow rate, base bleed area, and either bleed flow pressure drop or bleed flow velocity, one of which must be input if base bleed is specified (>0).

Table 1 (Page 1 of 5)

EBPA INPUT GLOSSARY

Name	Symbol	Location	Definition
THETA1	θ_1	001	Cone half-angle. When the vehicle is an elliptic cone, it is the half-angle along the minor axis. For a biconic vehicle it is the forebody half-angle (deg).
THETA2	θ_2	002	Body half-angle. When the vehicle is a cone this angle should be input equal to THETA1. For a biconic vehicle it represents the aft body half angle along the major axis (deg).
XBODY	X_{body}	003	Overall vehicle length. In the case of a cone or elliptic cone vehicle, the overall length is also equal to XCONE (ft).
XCONE	X_{cone}	004	The vehicle forebody length. The length of the conic section for a biconic vehicle. In the case of a cone or elliptic cone shaped vehicle this is also equal to the overall body length XBODY (ft).
MINF	M_∞	005	Free-stream Mach number.
ALT	ALT	006	Flight altitude. This variable is not used in any computations. It is for printout only (ft).
PINF	P_∞	007	Free-stream pressure (psf).
TINF	T_∞	008	Free-stream temperature (°R).
ALFA	α	009	Angle of attack (deg).
PHI	PHI	010	Wind angle or roll angle (deg).
ICG	I_{cg}	011	Vehicle center of gravity (ft).
GAMA	γ	012	Specific heat ratio of air.
POJET	P_j	013	Thruster chamber pressure (psi).
AOJET	A_j	014	Thruster nozzle throat area (in^2).
ERATIO	E_{ratio}	015	Ratio of nozzle exit area to nozzle throat area.

Table 1 (Page 2 of 5)

EBPA INPUT GLOSSARY

Name	Symbol	Location	Definition
ALFJ	α_j	016	Forward inclination of jet, measured from the normal to the vehicle surface (deg).
ZJET	Z_{jet}	017	Thruster site distance measured from the vehicle base (in).
BETA	β	018	Half-angle of nozzle exit cone.
KINDF	KINDF	019	Type of fuel. Select from one of the compositions listed in data block FRJIB.
KINDO	KINDO	020	Type of oxidizer. Select from one of the compositions listed in the data block FRJIB.
ETAR	η_R	021	Indicates frozen or equilibrium flow. 0-Frozen flow 1-Equilibrium flow ETAR may also be a fraction of equilibrium.
PCTR	PCT_R	022	Modifies the expression correlating the upstream part of the jet shock. Optimum values range between .7 and .9. The default is .8.
MO	M_L	024	Local Mach number.
PPO	P_L	025	Local pressure (psf).
PTO	T_L	026	Local temperature (°R).
PVO	V_L	027	Local velocity (ft/sec).
CCRIT	C_{crit}	029	The percentage of fuel to be considered in the Gaussian distribution.
DNI	DNI	030	Input not required.
NZONES	N_z	032	Number of mixing zones.
IPNT	PF_A	039	Print flag 0-Level one printout 1-Level two printout 2-Level three printout

Table 1 (Page 3 of 5)

EBPA INPUT GLOSSARY

Name	Symbol	Location	Definition
IPNT	PF_B	040	Chemistry print flag 0-No chemistry output 1-Chemistry printout at each computational station
PROG	P_C	050	Input not required.
OOVERF	O/F	064	Oxidizer over fuel ratio of the injectant.
THETAJ	θ_j	065	Angular location of the thruster relative to the vehicle centerline as viewed from the rear looking forward. A positive direction is counterclockwise (deg).
REFRAD	RE	066	Input not required.
RN	RN	067	Vehicle nose radius (ft). Defaults to 0.001 ft if not input.
LOCFLG	LC	068	Local condition flag 0-Local conditions are input 1-Free-stream conditions are input and local conditions are computed in subroutine LOCAL
NNOZZ	N_{nozz}	096	The number of individual nozzles around the vehicle periphery, near the base.
PHIBD	ϕ_B	097	The divergence angle, measured with respect to the body surface, of streamline entering the annulus external boundary at the base plane (deg).
SIGBD	σ_B	098	Mixing maximum-slope half angle for air and fuel injectant (deg).
CI	C_B	099	Fractional outer flow expansion angle from base. If zero or not input, no expansion occurs; full expansion if 1.0 is input.
PRTFLG	PF_P	101	Print flag for base flow computations. 0., Summary Report only = 1., Intermediate iterations, report. 2., All iterations, report.
RWF	RW_f	102	Ratio of experimental reattachment radius to base plane radius. If not input, the value is computed by an equation in the code.

Table 1 (Page 4 of 5)

EBPA INPUT GLOSSARY

Name	Symbol	Location	Definition
$DELTAO_1$	δ_{o_1}	103	Initial estimate of the divergence angle, measured with respect to the body surface, of streamline entering the annulus external boundary at the turning point for annulus 1. The estimate is used to start the streamline divergence interations. The default value is 0. Optimally, a table of equi-distant intervals can be generated (see $DELTNC_1$ below) using $DELTAO_1$ as the first table entry (deg).
$DELTAO_2$	δ_{o_2}	104	Same as δ_{o_1} for annulus 2.
$DELTAF_1$	δ_{f_1}	105	Final table entry for the streamline divergence angle for annulus 1 if the table option is used (deg).
$DELTAF_2$	δ_{f_2}	106	Same as δ_{f_1} for annulus 2.
$DELINC_1$	δ_{Δ_1}	107	Increment for streamline divergence angle for annulus 1 if the table option is used. The table option is invoked if $DELINC_1$ is input non-zero. The equi-distant table entries will consist of $DELTAO_1$, incremented in steps of $DELINC_1$, up to but not exceeding $DELTAF_1$.
$DELINC_2$	δ_{Δ_2}	108	Same as δ_{Δ_1} for annulus 2.
$THETWO_1$	$\Theta_{w_{o_1}}$	109	Initial estimate of the cavity half angle, measured with respect to the vehicle axis for annulus 1. The estimate is used to start the solution process of determining system performance. A value greater than zero should be input. Optionally, a table of equi-distant intervals can be generated (see $THWINC_1$, below) using $THETWO_1$ as the first table entry (deg).
$THETWO_2$	$\Theta_{w_{o_2}}$	110	Initial estimate of the innerflow half angle, measured with respect to the vehicle axis, for annulus 2; used to start iterations for the inner flow calculations. Its value must not be zero if flow for the 2nd annulus is to be generated (deg).

Table 1 (Page 5 of 5)

EBPA INPUT GLOSSARY

Name	Symbol	Location	Definition
$THETWF_1$	θw_{f_1}	111	Final table entry for cavity half angle for annulus 1 if the table option is used (deg).
$THETWF_2$	θw_{f_2}	112	Reserved.
$THWINC_1$	θw_{Δ_1}	113	Increment for cavity half angle for annulus 1 if the table option is used. The table option is invoked if $THWINC_1$ is input non-zero. The equi-distant table entries will consist of $THETWO_1$, incremented in steps of $THWINC_1$, up to but not exceeding $THETWF_1$. The default for $THWINC_1$ is 0.
$THWINC_2$	θw_{Δ_2}	114	Reserved.
DELTAR	δR	115	Step in annulus inner boundary radius at inner flow geometry transition; allows non-zero inner flowrate in annulus 2 when base bleed is zero (ft).
MDOTB	$\dot{m}_B$	116	Base bleed flow rate (lb/sec).
VMATCH	V_M	117	Defines the point on the inner shear layer at which the recirculation velocity profile is matched in velocity and gradient. Input presently not required.
AOB	A_{OB}	118	Total area of base bleed apertures (ft^2).
DELPBI	ΔP_B	119	Bleed flow pressure drop. If specified (>0), bleed flow velocity, V_B, is calculated (lb/ft^2).
VBI	V_B	120	Bleed flow velocity. If specified (>0), bleed flow pressure drop, ΔP_B, is calculated (ft/sec).

EXTERNAL BURNING PROPULSION ANALYSIS

LOADSHEET 2

[E] KEYPUNCH:
PUNCH IN ALL CARDS

MUST BE FILLED IN FOR PROPER PROCESSING

63–65	66–67	68–70	71–72
BO	RR	CASE	PART CASE

QUAN	LOC	VALUE
BASE GEOMETRY		
N_{NOZZ}	96	
ϕ_B	97	
τ_B	98	
[illegible]	99	
FW_F	102	
ANNULUS GEOMETRY		
δ_{c_1}	103	
δ_{i_1}	105	
δ_{Δ_1}	107	
$\theta_{w_{c_1}}$	109	
$\theta_{w_{i_1}}$	111	
$\theta_{w_{\Delta_1}}$	113	
δ_{c_2}	104	
δ_{i_2}	106	
δ_{Δ_2}	108	
$\theta_{w_{c_2}}$	110	
$\theta_{w_{i_2}}$	112	
$\theta_{w_{\Delta_2}}$	114	

QUAN	LOC	VALUE
BASE BLEED PARAMETERS		
ΔR	115	
$\dot{m}_B$	116	
V_M	117	
A_{OB}	118	
ΔP_S	119	
V_B	120	
PRINT FLAG		
PF_P	101	

KEYPUNCH: INPUT A-2

Figure 3 EBPA Sample Loadsheet 2

Section 3

PROCESSING FLOW

3.1 Executive Routine EBPA

The EBPA computer program uses an executive routine to control two individual subprograms FRJI and BBMODL as shown in Figure 4. In each subprogram, control is maintained by a driver routine which establishes the proper sequencing and calling logic for subordinate subroutines. An input data editing subroutine (INPUTA) is first called which reviews the data and sets up the data in terms of cases, reference runs, and basic decks and stores the edited data on disc. A single case is then input to core, and the two subprograms are sequentially executed based on the input data. When the computations are complete, control is returned to the INPUT routine for the next case of data. If there is none, program execution is terminated.

3.2 Fuel Rich Jet Interaction Subprogram FRJI

A flow diagram for the FRJI subprogram is given in Figure 5. The subprogram is activated by the executive control routine. The input data are listed, subprogram constants are computed, and variables are initialized. The local flow conditions immediately upstream of the injection nozzle are calculated by subroutine LOCOND for given free-stream conditions, angle of attack and bank angle. The conservation equations for energy, mass, and momentum in the upstream region are solved in the subroutine UPCON.

If the solutions of the equations converge, a summary of the upstream region is printed; otherwise, subprogram control is returned to the executive routine for new input data.

With the computations for the upstream region completed, the program proceeds to compute the downstream region. The subroutine controlling the downstream calculations is DNCON. A test is first made to determine if the downstream interval being calculated is the final one. The outer flow field is then calculated and also the cross-sectional area of the inner flow. At this point, the conservation equations for the downstream region are solved by iteration

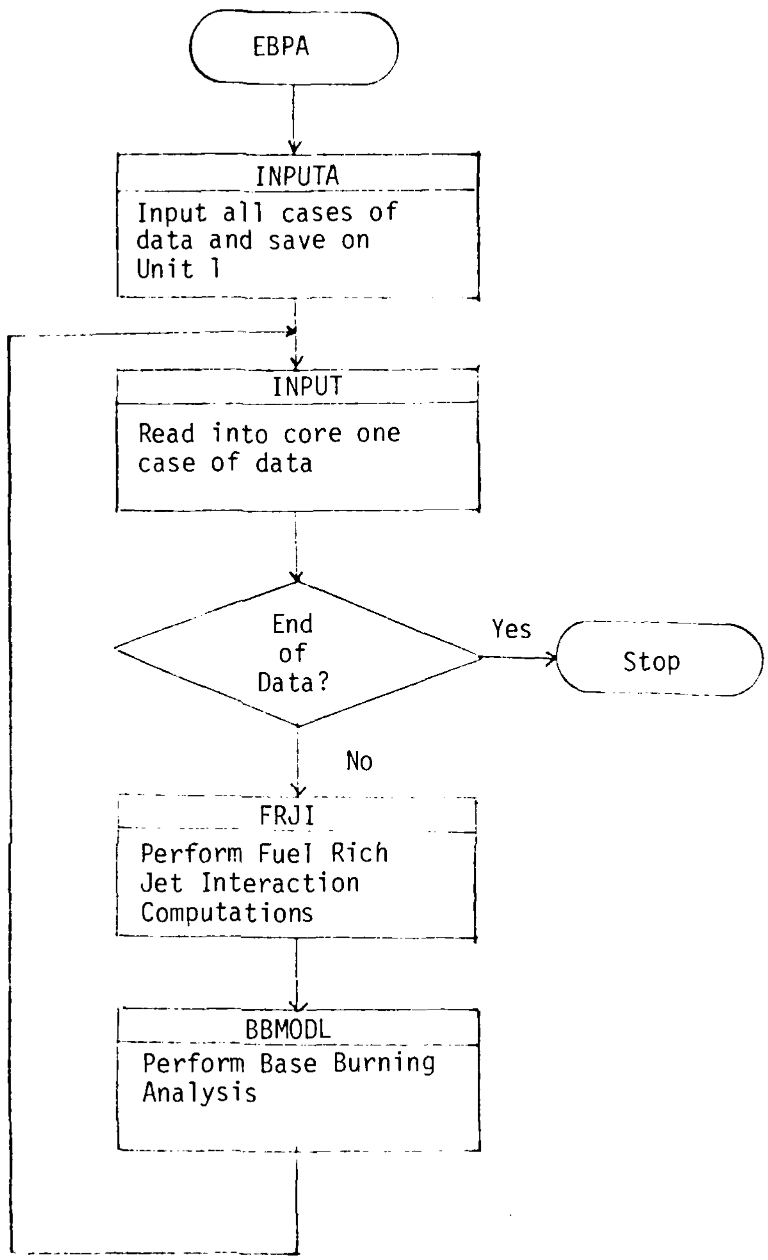

Figure 4 Flow Diagram of Executive Control Subroutine EBPA

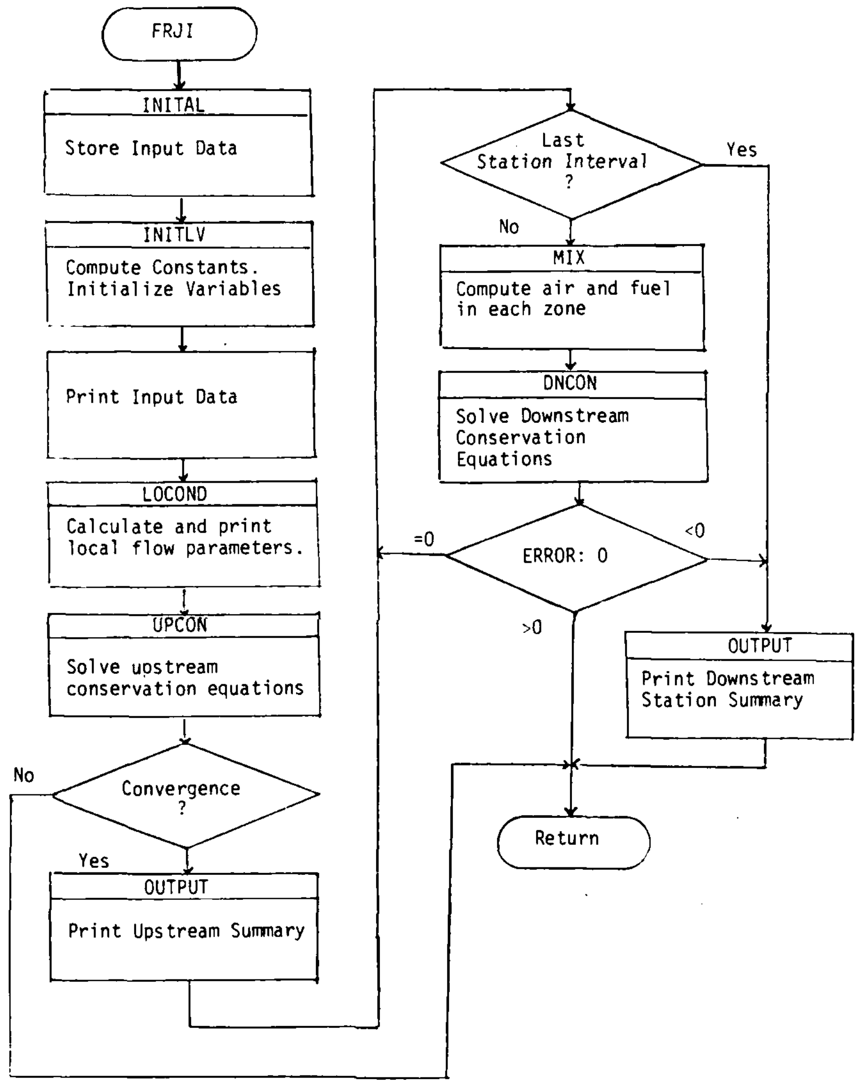

Figure 5 Flow Diagram for Subprogram FRJI

with chemistry. When convergence of the equations for the inner flow is achieved, a comparison is made of the pressures at the combustion boundary. If the pressures across the boundary are not equal, an adjustment is made in the boundary slope and the process of computing the outer flow field and the inner region is repeated. When convergence in the outer loop is achieved, a comparison is made of the pressures at the combustion boundary. If the pressures across the boundary are not equal, an adjustment is made in the boundary slope and the process of computing the outer flow field and the inner region is repeated. When convergence in the outer loop is achieved, control is returned to the subprogram FRJI, and the subroutine OUTER is entered at OUTERS and the variables in the outer flow field are dimensionalized. Forces are computed for the downstream segment and a summary printout is made. If the downstream segment is not the last one on the vehicle, the above process, starting with solution of the downstream conservation equations, is repeated. After the final segment has been processed, a tabulation of the flow field summary is produced. The subprogram is then returned to the executive control routine.

3.3 Base Burning Modeling Subprogram BBMODL

This subprogram computes the flow in the separated region behind the vehicle base plane. The flow conditions generated at the base by the FRJI subprogram, and user inputs, constitute the inputs to the subprogram. A flow diagram of BBMODL is given in Figure 6.

The inputs from loadsheet 2 are printed and, if no case termination error has occurred upstream of the base, processed to determine the method of flow generation. A case termination error causes control to return to the executive routine. Inner and outer flow, flow rates and thermochemistry at the base plane are then saved, and working variables initialized.

A value of the cavity half-angle for the first annulus is calculated. A value for the streamline divergence angle at the turn for the first annulus is then computed. The annulus number is set, initial and constant flow parameters, constant geometry, and outer flow expansion computations are made for the annulus and, if requested, printed. Chemistry parameters are also retrieved, if required, for the first annulus.

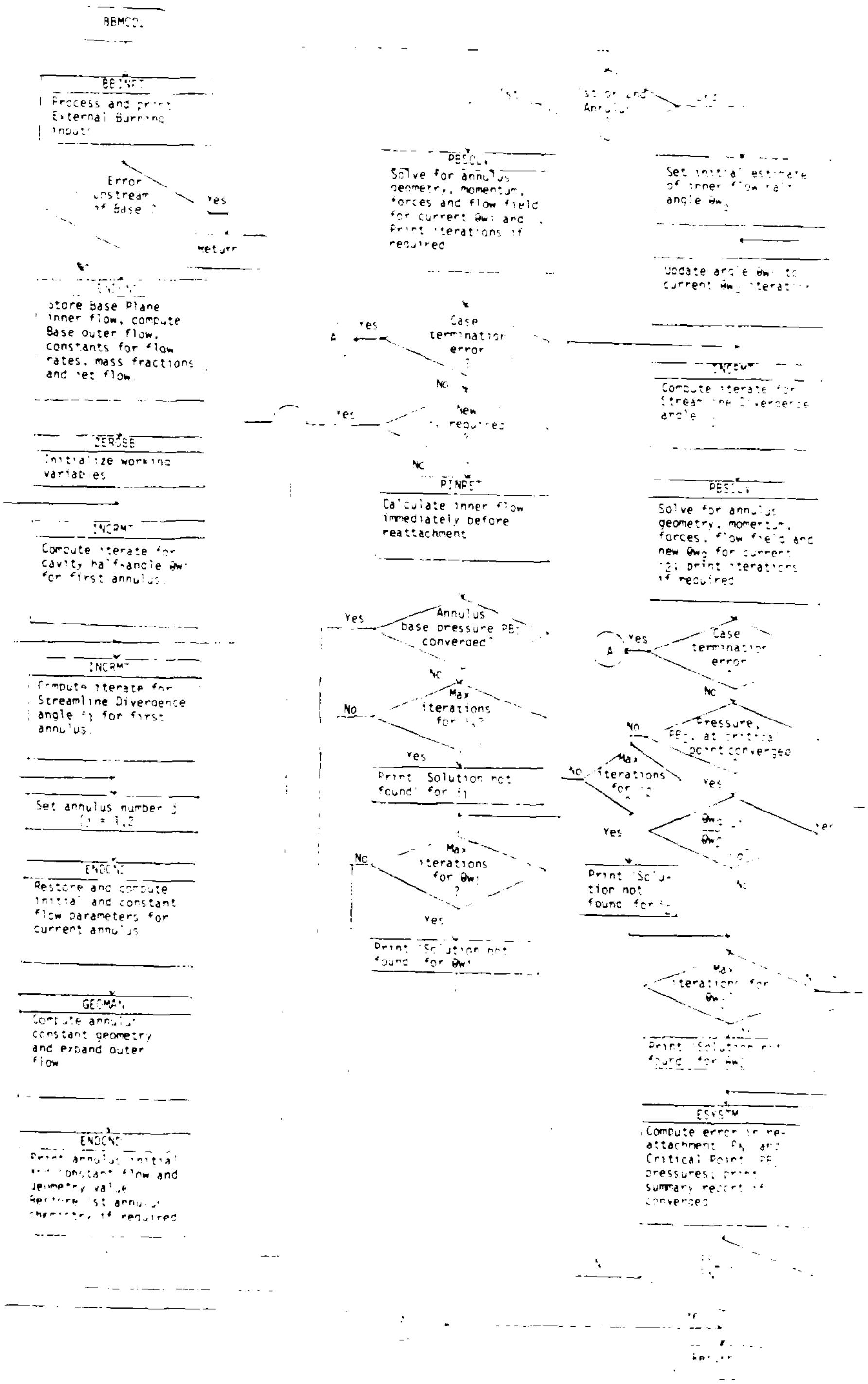

Figure 6 Flow Diagram for Subprogram BBMODL

A test is then made to determine if flow calculations are to be made for annulus 1 or 2. If computations are for the first annulus, annulus geometry, momentum, forces, base pressure, and the flow field for the current cavity half angle θw_1 and streamline divergence angle δ_1 are generated and, if requested, printed. If no case termination error occurred or a new δ_1 is not required as a result of low temperature or geometry inconsistency, the inner flow just before reattachment is calculated. If a case termination error occurs, the subprogram is returned to the executive control routine for a new case of data. If a new δ_1 is required, δ_1 is advanced and computations repeated using the new δ_1. If the calculated base pressure P_{B_1} (or P_{i+1}) differs relatively from the outer bounding pressure $Pout_d$ downstream of the turn in flow by less than a pre-assigned tolerance, P_{B_1} is considered converged for the current θw_1 and δ_1. Calculations then proceed to the second annulus.

If a pressure solution does not yet exist, and the maximum number of attempts advancing δ_1 has not been used, a new δ_1 is computed and the flow calculations repeated. If the maximum number of attempts in δ_1 has occurred, a diagnostic is printed, a new θw_1 is determined and all calculations for the annulus are then repeated. If the maximum number of computations for a θw_1 occurs, a diagnostic is printed and control is returned to the executive routine for a new case of input data.

The second annulus is entered on convergence of P_{B_1} (annulus 1). Chemistry parameters of annulus 1 are saved. Initial and constant flow parameters, constant geometry, and outer flow constants for annulus 2 are generated and, if required, printed. An inner flow half angle θw_2 for the annulus is estimated. A value for the streamline divergence angle δ_2 at the flow turn is then computed. The annulus geometry, conservation, flow field and a new θw_2 from the geometry are computed. Output is printed if requested. If no case termination error occurred, the pressure P_{B_2} at the critical point is tested for convergence. A case termination error causes control to return to the executive routine for a new case of input data. If there is P_{B_2} convergence, a test is made to determine the change in the previous and present θw_2 at the P_{B_2} convergence. If the change is within tolerance, the relative system error between the inner flow pressure P_N at reattachment and P_{B_2} is computed and

tested. If the error is within tolerance, the system solution has been achieved, a Summary Report of the results is output, and return is then made to the executive routine for a new case of input data.

If P_{B_2} has not converged for the current Θw_2 and δ_2, a new δ_2 is found and flow computations repeated. If the maximum number of computations for δ_2 has occurred, a diagnostic is printed, Θw_2 is updated from the latest computation and the annulus 2 computation process is repeated with the current Θw_2. If there is P_{B_2} convergence but change in the previous and present Θw_2 at the P_{B_2} convergence is not within tolerance, Θw_2 is updated to the present value and annulus computations repeated. When the maximum number of Θw_2 updates occurs, a diagnostic is printed and the system error calculated. If the relative system error in P_{B_2} and P_N is not within tolerance, control is returned to annulus 1, a new Θw_1 for the first annulus is determined from the system error, and the entire process of the above calculations is repeated. The repetitions continue until the system error is within tolerance or the maximum number of computations for Θw_1 has occurred.

Section 4

INSTRUCTIONS FOR USE

4.1 Program Activation and Control

The following is an example of the control card sequence of instructions and deck setup required for activation and execution of the EBPA program.

To execute the program on the CDC 6600 from tape with source card images:

CCl

```
    JOB,T400,P2,MT2. (Accounting)
    LABEL,EBPA,R,D=HY,L=EBPAPS,VSN=Reel #.        Source Card images file
    REQUEST,TAPEW,HY,VSN=Reel #.                  Chemistry Tape
    REWIND(EBPA,TAPEW)
    FTN(I=EBPA,R=3,PL=50000)                      Compile with full cross
                                                  reference and page limit.
    RETURN(EBPA).
    MAP,ON.                                       Prints full loader map.
    SEGLOAD.                                      Invoke program segmentation.
    LDSET,PRESET=NGING.                           Set core to negative
                                                   infinites.
    LGO.                                          Execute program.
    7-9-8 Card                                    Multi-punch end of record
        SEGLOADer directives                      card.
        See below
    7-8-9 Card
        Data Cards
    7-8-9 Card
    6-7-8-9 Card                                  Multi-punch end of job card.
```

The default file names for the input, output and chemistry tape files are, respectively, INPUT, OUTPUT, and TAPEW. If the program input data resided on file INPDAT, the program output written on file OUTDAT, and file CDAT contained the chemistry tape, the LGO card would become: LGO(INPDAT,OUTDAT,CDAT).

The SEGLOADER directives for the CDC 7600, CYBER 174 and CDC 6600 are listed below. For the CYBER and 6600, XTOI = and IOCON. are not required.

```
CC1       CC11        CC21

EBPAT     TREE        EBPA=(FRJI,BBMODL,INPUTA)
EBPA      INCLUDE     DEFIOJ,LINDEP,REACT,SETUP,FRJIB,RFJIA,INITLV
EBPA      INCLUDE     DECODE=,ENCODE=,FLTOUT=,ENDFIL=,EOF,XTOI=
EBPA      INCLUDE     FLTIN=,INCOM=,INPC=,KRAKER=,OUTB=
EBPA      GLOBAL      BILL,BODY
EBPA      GLOBAL      CHEM1,CHEM2,CHEM3,CHEM4,CHEM5,CHEM6,CONST2
EBPA      GLOBAL      DNCON1,DNCON2,DSDATA,ERREX
EBPA      GLOBAL      FACTOR,FLIGHT,FLOW,FMDOTS,FUEL
EBPA      GLOBAL      GIRLP,HEAD,INPUT,JET,JPEN,LOCAL1
EBPA      GLOBAL      MAIN,MAIN1,MAIN2,MAS1,MAS2,MAS3,MAS4,MAS5
EBPA      GLOBAL      MIX1,MIX2,MIX3,MARKAB,MOCOMP,MIXE92,OUTER9
EBPA      GLOBAL      OUTER1,OUTER2,OUTER3,OUTER4,OUTER5,OUTER6,OUTER7,OUTER8
EBPA      GLOBAL      QZERO,SBODY,SIDATA,SUMSAF,TEMPTF,TRASH,UPCON1
EBPA      GLOBAL      ZERO,ZNOUT
EBPA      GLOBAL      CONE,DCOSNE,FRSTRM,THRDEE
EBPA      GLOBAL      Q8.IO.,IOCON.,IO.BUF.,ALLIN,MLIST,IFLAG
          END         EBPA
```

4.2 Preparation of Input Data

The EBPA program includes a general purpose data input editor subroutine which converts data from punched cards to machine-internal formats acceptable to the program. The subroutine provides a method of loading numeric and alphabetic information into core, of partitioning the data into groupings, and of minimizing the high rate of redundancy in data that has to be read into the program. This Basic Deck-Reference Run-Case hierarchy of data groupings is discussed below. The following material discusses the data card formats permitted by the program.

4.2.1 Card Formats

Format 1 - Job Title Cards

This input format is used for loading alphameric data, Figure 7. Column 1 contains an 8-3 ("=") punch. Columns 2-5 contain the location within the array in which the first data word is to be stored. Columns 6-53 are used for loading alphameric information, eight words per card. These eight words in columns 6-11, 12-17, 18-23, 24-29, 30-35, 36-41, 42-47, and 48-53 will be stored in the relative locations LOC through LOC+7, respectively. Columns 54-62 should not be used.

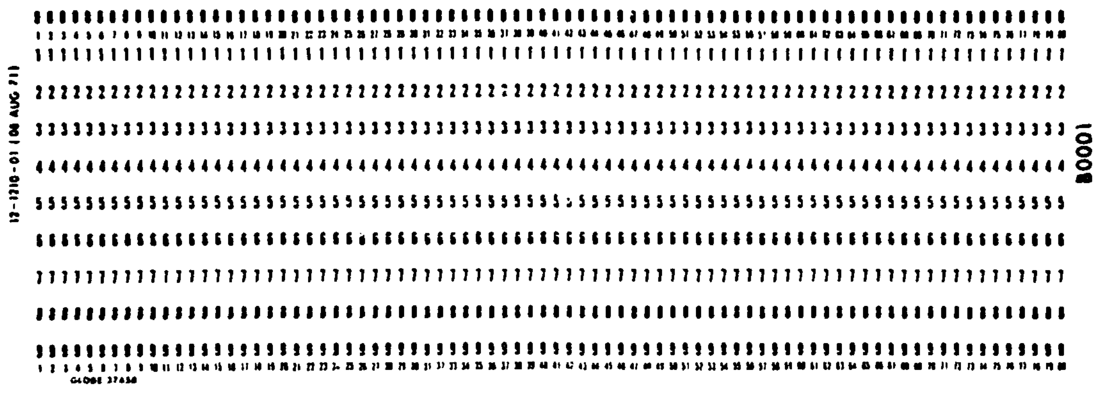

Figure 7. Job Title Card

The standard 80-column FORTRAN coding sheet may be used in lieu of a load-sheet. Column 1 must contain an equal sign ("="); columns 2-5 contain the location within the data array of the first word on the card; columns 6-53 contain the eight six-character words to be loaded; and columns 63-72 carry the BD, RR, and CASE numbers. Columns 54-62 should not be used.

Format 2 - Numeric Data

This format is designed for entry of real number values. A card guide for entering the values is shown in Figure 8. Column 1 must contain a 12-5 ("E") punch. Columns 2-61 are used for entering real number data, five fields per card. Columns 2-4, 14-16, 26-28, 38-40, and 50-52 contain the location within the array in which the data is to be stored. Columns 5-13, 17-25, 29-37, 41-49, and 53-61 contain the values of the elements.

In the loadsheet entry for this format, the Column 1 space must contain an "E". The QUAN column is for the programmer's reference only, and is not to be punched. The LOC column is used to identify the location of the data within the one-dimensional data array. The values of the elements are entered in the VALUE column, up to nine characters, including the sign, decimal point, and E type exponent, if used.

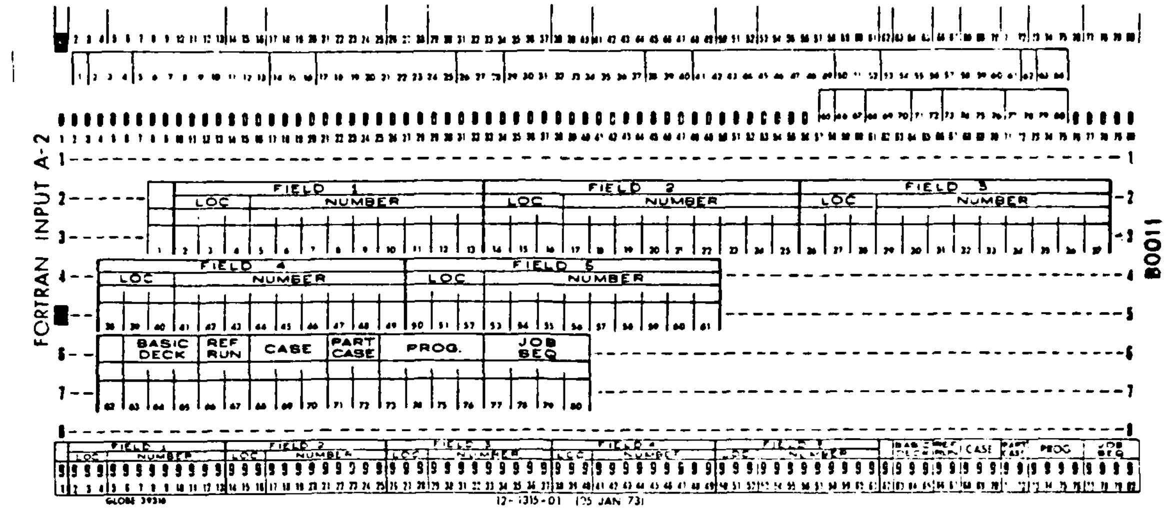

Figure 8 Numeric Data Cara

The permissible variations in the way these data may be entered are:

A. Plus signs may either be punched or omitted, but minus signs must be punched.

B. For numbers using E conversion, (i.e., 2.5E01), the start of the exponent field must be indicated by an "E", or by a plus or minus sign--the start of the field cannot be indicated by a blank.

C. The decimal point must be punched to insure that the value will be interpreted correctly.

D. The exponent, if any, must be right justified in the field.

E. The INTEGER value in the LOC field must be right adjusted.

The following applies to <u>all</u> input data cards:

Cards with a zero or a blank in column 1, and cards with any punch other than a zero or a blank in column 62 will be ignored. Columns 63-65 contain the Basic Deck number; columns 66-67 contain the Reference Run number; and columns 68-70 contain the CASE number. Columns 71-76 should remain blank. Columns 77-80 may be used for the job sequence number or other identification. All data cards must be in sort, major to minor, columns 63-70.

4.2.2 Basic Deck-Reference Run-Case Data Input Capabilities

A proper definition of terminology is essential to a discussion of data input editor capabilities. Many misconceptions on this subject are the result of using terminology which is loosely defined. To avoid such confusion, the terminology for this discussion is defined below. The user is advised to refer to this list of basic definitions from time to time.

Case Study - A computerized simulation of some process for a defined set of parameters.

Run - The groups of data required for one or more case studies, and which are collectively submitted at one time to be processed by a computer program.

Set of Data - The data that are required for a case study.

Data Element - One of the items of data in a set of data.

BASIC DECK - REFERENCE RUN - CASE Hierarchy - The hierarchical organization of data elements used in a case study. This hierarchy is based on the degree of constancy each particular data element exhibits from one case study to the next.

Data Level of a data element - The place in the BASIC DECK - REFERENCE RUN - CASE hierarchy at which that data element is defined for a particular case study. If a data element is defined in a BASIC DECK (BD), a REFERENCE RUN (RR), or a CASE, its data level is respectively the BD-level, the RR-level, or the CASE-level.

BD Data - The collection of data elements which is defined at the BD-level, and which contributes to the typical set of data being discussed (versus all data elements in the run which are defined at the BD-level). The term is sometimes shortened to "BD." BD data have the highest degree of constancy from one case study to the next.

RR Data - The collection of data elements which is defined at the RR-level, and which contributes to the typical set of data being discussed (versus all data elements in the run which are defined at the RR-level). The term is sometimes shortened to "RR." RR data have some lesser (than BD) degree of constancy from one case study to the next.

CASE Data - The collection of data elements which is defined at the CASE-level, and which contributes to the typical set of data being discussed (versus all data elements in the run which are defined at the CASE-level). The term is sometimes shortened to "CASE" or "CS." CASE data are unique to a case study.

Data Origin - The location in computer memory where the first element of a group of related data elements is stored.

Part Case Data - The collection of data elements which results when a set of data is partitioned into several smaller groups. This term is sometimes shortened to "PC." PC data can occur at any level of the BD-RR-CASE hierarchy.

Domain of an RR - Consists of the grouping of CASE data for all case studies which use that RR to define data elements.

Domain of a BD - Consists of the groupings of RR data and CASE data for all case studies which use the BD to define data elements.

Basic Deck, Reference Run, and Case

BD, RR, and CASE capability is designed to facilitate handling of data input from punched cards where there is a high degree of redundancy.

Concept of Reference Run and Case

Because of the nature of computer applications often encountered, experience has shown that a typical program's user will read a quantity of data which describes a basic model; the user will then change the values of a few parameters and generate "case studies" for different variations from that basic model. The purpose of the RR and CASE concept is to provide such a user the facility to refer back to a particular data set used earlier (the basic model) and to instruct the computer to use that data set again, with certain specified changes. The typical data set will thus contain data elements from two sources: RR data consist of those data elements of a set of data which stay the same (i.e., which are referenced) from one case study of a basic model to the next; CASE data consist of those data elements of a set of data which are unique to a particular case study.

Example of Reference Run and Case

Suppose one wanted to simulate the flight of a missile over a given trajectory, varying several parameters which define the missile's shape and calculating the resultant effect on the missile's surface temperatures. In this instance, the trajectory data would ideally be defined as the RR data; the missile shape parameters would constitute CASE data. One set of data representing one simulated flight of the missile over the trajectory would be defined by the RR data and a particular CASE; a second set of data representing a simulated flight of a modified missile over the same trajectory would be defined by the RR data, but with a different CASE. The collection of the RR data and the individual CASEs (which comprise that RR's domain) might constitute the run.

Use of Reference Run and Case Data

When using the INPUTA subroutine, the user specifies which data items are RR data and which are CASE data. By careful selection as to what he includes in the RR category, the user can minimize the chore of data transcription onto loadsheets. The user must follow certain conventions when using RR and CASE capability. Failure to follow these conventions or failure to have a clear understanding of the process may result in the computer program either indicating a data error or interpreting the data in an undesired manner.

A. Both RR and CASE data are identified by numbers. These numbers are assigned by the user and are physically punched in the cards which contain the corresponding data elements.
   1. The user defines a set of RR data by assigning a two-digit nonzero RR number (e.g., "01," "27," "83"). The CASE number field for that RR data must be defined as "000." These two numbers will be punched in all data cards which define that RR.
   2. The user defines CASE data by assigning a three-digit, nonzero CASE number (e.g., "001," "270," "508"). He must also specify the applicable RR number. These two numbers will be punched in all data cards containing the data elements which define that CASE.

B. If the user wants to study more than one basic model in a run, he can define as many as 99 sets of RR data, such that each set has a unique RR number. CASE number assignments need be unique only within the domain of a given RR. Thus, one run could contain the two unrelated sets of data identified as "RR 1 CASE 5" and "RR CASE 5).

C. An RR number of "00" exists, but cannot be used to define RR data. Such a designation is punched on CASE data cards when a run (or part of a run) is being made which does not require RR capability, or in instances when BD is being used (to be discussed later).

D. Both the RR and CASE fields on the punched data cards must be completely punched with numerics (the digits 0 through 9). When computer operations keypunches the data, blanks are replaced by zeros.

E. The load sheet forms define the RR number (occupying two card columns for its two digits) and the CASE number (occupying three card columns for its three digits) in two adjacent fields; the RR number field is to the left of, and hence higher-ordered than, the CASE number field.

F. The data cards for a run must be ordered so that successive cards present RR and CASE numbers which, if read together as one number, define a monotonically increasing sequence. RR data must be defined in the sequence of data cards prior to any CASE data in its domain. All CASE data cards that refer to a given RR number must be contiguous and ordered, and must adjoin those data cards which define the RR.

G. The computer program will not accept RR data by itself. Program execution using a set of data is initiated by the reading of CASE data. The minimum CASE consist of one punched card with at least one data item punched on that card in the left-most data field.

H. When the user is assigning his data to the RR and CASE categories, he should remember that a set of data is effectively generated by reading the RR data into memory, then overlaying it with those data items defined in the CASE data. By this overlay process, data items not defined in the RR data are assigned a value if defined in the CASE data; data items defined in the RR data are assigned

the substitute value as (and if) redefined in the CASE data; data items not defined in either the RR or CASE data are assigned a value of zero. Successive sets of data in that RR's domain are generated in the same manner, the CASE data always overlaying the original RR data.

I. As a corollary to item G, it is seen that in a given RR's domain, one CASE is independent of another. A given CASE in that domain can temporarily (i.e., for that set of data) change items defined in the RR.

Concept of Basic Deck

The purpose of BD capability is to provide the RR-CASE user with an extension of that facility. BD data has a relationship to RR data that is similar to the relationship of RR data to CASE data. The BD-RR-CASE concept is useful for programs whose data structure is complicated in the degree of its relative constancy from one case study to the next. In such instances, a typical set of data will contain data elements from three sources: BD data, RR data, and CASE data. As a general rule, BD data consist of those data elements of a set of data which have the highest degree of constancy from one case study to the next. RR data consist of those data elements of a set of data which have some lesser degree of constancy from one case study to the next.

Example of Basic Deck

Suppose one wanted to simulate the flight of three different missiles over a given trajectory, varying several parameters defining each missile's shape, and calculating the resultant effect on each missile's surface temperature. In this instance, the trajectory data would ideally be defined as the BD data; each missile's basic shape parameters would constitute an RR. Variations in these shape parameters would constitute CASE data. One set of data representing one simulated flight of the first basic missile shape over the trajectory would be defined by the BD data, the RR data for that missile shape, and the CASE data defining one variant of the shape parameters. A second set of data representing a simulated flight of that same basic missile, but with slight modifications, over that same trajectorv, would be defined by

the BD data, the same RR data, but with a different CASE. A third set of data representing a simulated flight of the second basic missile shape over the same trajectory would be defined by the same BD data, but with a second set of RR data, and one of the CASEs in that second RR's domain. The collection of BD, RR's and CASE's might constitute the run.

Use of Basic Deck Data

When INPUTA is used to provide a BD capability, the following rules apply. The rules defined for RR and CASE remain applicable, unless specifically noted otherwise. The user must follow certain conventions when using BD capability. These conventions are simply extensions of those defined in the RR and CASE discussion, with similar consequences if not practiced.

A. BD data are identified by number. BD numbers are assigned by the user and are physically punched into the cards which contain the corresponding data elements.
   1. The user defines a set of BD data by assigning a three-digit BD number (e.g., "021," "146," "938"). The RR and CASE number fields for that BD data must be respectively defined "00" and "000." These three numbers will be punched in all data cards which define the BD.
   2. In defining RR data, the user must specify the applicable BD number. That BD number will be punched in all data cards which define that RR. Similarly, in defining CASE data, the applicable BD and RR numbers must be punched in all data cards which define that CASE.

B. As many as 999 unique sets of BD data can be defined in one run. RR number assignments need be unique only within the domain of a BD. Thus, one run could contain the two unreleased sets of data identified as "BD 1 RR 5 CASE 6" and "BD 2 RR 5 CASE 6."

C. A BD number of "000" exists but cannot be used to define BD data. Such a designation is punched on RR and CASE data cards when a run (or part of a run) is being made which does not require BD capability. Similarly, an RR number of "00" can be used when a CASE need only refer to a BD.

D. The BD field on punched data cards must be completely punched with numerics. When computer operations keypunches the data, blanks are replaced by zeros.

E. The loadsheet forms which allow the BD capability define the BD number field (occupying three columns for its three digits) to the left of and adjacent to the RR number field.

F. The data cards for a run must be ordered so that successive cards present BD, RR, and CASE numbers which, if read together as one number, define a monotonically increasing sequence. BD data must be defined in the sequence of data cards prior to any RR or CASE data in the BD domain. RR and CASE data cards that refer to a given BD number must be contiguous and ordered, and must adjoin those data cards which define the BD.

G. The computer program will not accept BD or BD/RR data by itself. Program execution using a set of data is initiated by the reading of CASE data. The minimum CASE consists of one punched card with at least one data item punched on that card in the left-most data field.

H. When the user is assigning his data to the BD, RR and CASE categories, he should remember that a set of data is effectively generated by: (1) reading the BD data into memory, (2) overlaying it with those data items defined in the RR data (if any), and (3) overlaying this "intermediate result" with those data items defined in the CASE data. (The overlaying process is the logical extension of that described in RR and CASE. RR has the same relationship to BD that CASE has to RR.) Successive sets of data in that BD's domain are generated in the same manner, the RR and CASE data always successively overlaying the original BD data.

I. As a corollary to item G, it is seen that RR's in a given BD's domain are independent of each other. A given RR in a BD's domain can temporarily (i.e., for all CASE's in its domain) change items defined in the BD. A given CASE in an RR's domain can temporarily (i.e., for that set of data) change items defined in its associated RR or BD.

Examples of BD-RR-CASE

Some examples of BD-RR-CASE number sequencing of data cards are as follows:

BD	RR	CASE	
000	00	001	1 set of case data only
000	00	001	
000	00	004	2 sets of case data only
000	00	006	
000	01	000	
000	01	002	1 RR with 2 data cases
000	01	003	
001	00	000	
001	00	003	1 BD with 2 data cases
001	00	005	
002	00	000	
002	04	000	1 BD with 1 RR and 1 Case
002	04	005	
005	00	000	
005	03	000	
005	03	008	
005	03	009	1 BD with 2 RR's and 2 cases for each RR
005	04	000	
005	04	010	
005	04	011	

4.2.3 Chemistry Tape Format

The chemistry tape contains, primarily, coefficients for computations of enthalpy, entropy, and specific heat for each of the atomic species utilized by the program. The data are read in subroutine SEARCH and the coefficients are used in subroutine GIBBS. The tape is written in binary (unformatted) mode and tape density (bits per inch) is set at generation.

Three records of information are provided for each species. The record formats and contents are described as follows.

	Variable(s)	Definition/Usage
Record 1		
Word 1	LEVEL	INTEGER indicating coefficient data to read if ≥ 0; end of data if < 0.
Word 2	JAN	INTEGER specifying record length for coefficient data: = 1, 8 words = 2, 16 words
Word 3	KHASE	= 0, flags specific counter
Word 4	SPECIE:	Alphanumeric atomic symbol for its species.
Record 2		
Words 1-14	$IE_{i,j}$ i=1,..., 7 j=1,2	Atomic description INTEGER array providing for 7 atomic elements j=1: number of atoms j=2: atomic number
Record 3		
Words 1-8 or Words 1-16	RA,RB,RC,RD / RA,RB,RC,RD, RE,RF,TL,TU	Arrays of floating point coefficient data. Record length $\leq$ 10 if JAN=1 or 16 if JAN=2.

The record formats are repeated for each species.

Section 5

OUTPUT

Three levels of printed output have been provided for the EBPA program. The level selection of printout is specified by the PF_A and PF_B input flags in locations 039 and 040 of loadsheet 1 (Figure 1) and PF_P at location 101 of loadsheet 2 (Figure 3). The input values for these flags are discussed in Section 2. Flags PF_A and PF_B pertain to output generated upstream of the base plane by the FRJI portion of the program, and PF_P to output generated in the annulus regions by the BBMODL Subprogram.

5.1 Summary Level Output

Tables 2 through 6 provide the normal or basic mode of output for the program. This level of output is obtained by a zero or blank for the values PF_A in location 039 of loadsheet 1 and PF_P in location 101 of loadsheet 2. Table 2 lists the user inputs from loadsheet 1 and consists of vehicle, flight and injector parameters, propellant and chemical flow parameters, the determined local and jet conditions, jet thermochemistry, and the propellant's chemical composition. Table 3 is a summary of upstream region results generated at the completion of the upstream solution. Station data tabulations are generated after all computations for each station have been made. A flow field summary, Table 4, tabulates station distance, inner shock layer radius, shock cross-sectional area, and chemical/physical properties for each station. The tabulations in this table include the last upstream station and all downstream stations. The location of the interface between the upstream and downstream regions is defined by the penetration height of the jet.

Table 5 consists of the inputs from loadsheet 2. These inputs are used with inputs from loadsheet 1 and results of the base plane for calculations in the base control region. Table 6 is abbreviated output of the final iteration in θ_{W1} for the system solution. Included are the half angles, divergence angles, pressures, and the relative error in the system solution. Table 7 represents a Summary Report of the EBPA program.

Table 2 JI Inputs

EXTERNAL BURNING PROPULSION ANALYSIS
BASIC DECK 20 REFERENCE RUN 1 CASE 601 PAGE 1

[illegible] RESULTS: REPORT [illegible], APRIL 1977

PROGRAM INPUTS

VEHICLE PARAMETERS:				
FIRST HALF CONE ANGLE	THETA1	=	18.00	DEGREES
SECOND HALF CONE ANGLE	THETA2	=	.01	DEGREES
LENGTH OF VEHICLE	XBODY	=	[illegible]	FEET
LENGTH OF CONE	XCONE	=	.50	FEET
THRUSTER ANGLE	THETAJ	=	.00	DEGREES
FLIGHT PARAMETERS:				
MACH NUMBER	MINF	=	6.00	(DIMENSIONLESS)
ALTITUDE	ALT	=	0.	FEET
PRESSURE	PINF	=	[illegible]	POUNDS PER SQUARE FOOT
TEMPERATURE	TINF	=	540.00	DEGREES RANKINE
ANGLE OF ATTACK	ALFA	=	0.00	DEGREES
BANK ANGLE	PHI	=	0.00	DEGREES
VEHICLE CENTER OF GRAVITY	XCG	=	1.03	FEET (MEASURED FROM NOSE)
RATIO OF SPECIFIC HEATS	GAMA	=	1.40	(DIMENSIONLESS)
INJECTOR PARAMETERS:				
CHAMBER PRESSURE	PCJET	=	89.70	POUNDS PER SQUARE INCH ABSOLUTE
THROAT AREA	ASJET	=	.00087	SQUARE INCHES
EXPANSION RATIO	ERATIO	=	1.01	(DIMENSIONLESS)
INCLINATION OF JET	ALFAJ	=	0.00	DEGREES
INJECTOR SITE DISTANCE	ZJET	=	1.00	INCHES (MEASURED FROM VEHICLE BASE)
HALF ANGLE OF NOZZLE EXIT CONE	BETA	=	10.00	DEGREES
PROPELLANT:				
FUEL	NUMBER		9	ALUMINIZED COMPOSITE
OXIDIZER	NUMBER		9	ALUMINIZED COMPOSITE
OXIDIZER-FUEL RATIO	OOVERF	=	1.00	(DIMENSIONLESS)
PROGRAM FLOW PARAMETERS				
FROZEN/EQUILIBRIUM CHEMISTRY	ETAR	=	0.00	(DIMENSIONLESS)
NOSE RADIUS MULTIPLIER	PCTR	=	.7000	(DIMENSIONLESS)

Table 2 JI Inputs (continued)

EXTERNAL BURNING PROPULSION ANALYSIS
BASIC DECK 20 REFERENCE RUN 1 CASE 601 PAGE 2

SCHADOW AND CHIEZE RESULTS REPORT AFRPL-TR-79-10, APRIL 1979

LOCAL CONDITIONS

MACH NUMBER	MO	=	2.0000	(DIMENSIONLESS)
PRESSURE	PLOC	=	1944.80	POUNDS/SQUARE FOOT
TEMPERATURE	TOO	=	940.01	DEGREES RANKINE
VELOCITY	VLOC	=	[illegible]	FEET/SECOND
DENSITY	ROLOC	=	.0020900	SLUGS/CUBIC FOOT
DYNAMIC PRESSURE	QLOC	=	5442.98	POUNDS/SQUARE FOOT
LOCAL FLAG	LOCFLG	=	1	

JET CONDITIONS

MACH NUMBER	MJET	=	1.0843	(DIMENSIONLESS)
EXIT TEMPERATURE	TJET	=	2123.63	DEGREES RANKINE
EXIT VELOCITY	VJET	=	[illegible]	FEET/SECOND
EXIT DENSITY	ROJET	=	.0010837	SLUGS/ CUBIC FOOT
MOLECULAR WEIGHT	MOLWTJ	=	30.456	(DIMENSIONLESS)
RATIO OF SPECIFIC HEATS	GAMAJ	=	1.1291	(DIMENSIONLESS)
JET THRUST	FR	=	2.02	POUNDS
JET MASS FLOW RATE	MDOTJ	=	.01470	POUNDS/ SECOND

JET THERMOCHEMISTRY

TOTAL ENTHALPY		
PROPELLANT	-196.040	CAL/GRAM
PRODUCTS	-1210.035	CAL/GRAM
HEAT RELEASE	1013.995	CAL/GRAM
EXIT ENTHALPY	-287.961	CAL/GRAM
SPECIFIC HEAT	.57048	CAL/GRAM/DEG K

CHEMICAL COMPOSITION OF PRODUCTS

SPECIE	MOLE PERCENT	WEIGHT PERCENT
[illegible]	[illegible]	[illegible]
H2	[illegible].7149	5.6734
ALNS	7.9207	10.1208
AL2O3S	7.0943	23.6147
CO	6.8977	6.3067
ALCL	[illegible].8522	11.9966
AL4C3S	1.2884	6.0797
AL	.385734E+00	.297306E+00
AL2O	.273336E+00	.627834E+00
ALCL2	.299913E+00	.821234E+00
H	.186502E+00	.617223E-02
C2H2	.169629E+00	.145012E+00
HCL	.117008E+00	.140081E+00
ALH	.101028E+00	.928349E-01
CH4	.768192E-01	.404685E-01
CNH	.394801E-01	.314856E-01
N2	.139183E-01	.128024E-01
CH3	.634257E-02	.313088E-02

Table 2 JI Inputs (continued)

[illegible]	.309745E-03	.135612E-02
CL	.187163E-03	.217881E-03
ALOCL	.163280E-03	.420435E-03
CHO	.844046E-04	.613616E-04
NH3	.415089E-04	.232116E-04
CO2	.216800E-04	.313270E-04
CH2O	.120247E-04	.118946E-04
ALO	.496853E-05	.701120E-05
CH2	.142362E-05	.659689E-06
CH3CL	.887449E-06	.147117E-05
CN	.875869E-06	.594277E-06
NH2	.847172E-06	.207867E-06
NO	.382783E-06	.213749E-06
AL2O	.336491E-06	.949659E-06
ALC	.179749E-06	.230107E-06
NH	.890319E-07	.419310E-07
CN	.799307E-07	.341681E-07
C2N2	.868790E-07	.114287E-06
ALHO	.431827E-07	.623682E-07
ALN	.339863E-07	.497360E-07
C3	.132139E-07	.186325E-07
C	.189180E-07	.809417E-08

Table 3 Upstream Region Summary

```
                         EXTERNAL BURNING PROPULSION ANALYSIS
                   BASIC DECK  20     REFERENCE RUN  1     CASE 601                                   PAGE  3

              SCHADOW AND CHISEL RESULTS    REPORT AFRPL-TR-79-40, APRIL 1979

                                        UPSTREAM REGION SUMMARY

FORCE INTEGRATION                      FLOWFIELD                                THERMODYNAMICS

NORMAL INTERACTION FORCE (LBS)         FLOW RATES (LBM/SEC)                     AIR
  INNER                        0.00      AIR                  .007120             ENTHALPY          100.898 BTU/LBM
  OUTER                        0.00      JET                  .014689
  TOTAL                        0.00      TOTAL                .023810             AVG VEL           5228.88 FT/SEC
JET THRUST                     2.02    STREAMTUBE DATA                          INNER MIXTURE
                                         PRESSURE         [illegible].34 PSF      ZONES             1
                                         TEMPERATURE        1900.76 DEG R         ETAR              0.00
GEOMETRY  (FEET)        FROZEN  REACTION DENSITY            .000360 LBM/CU FT   MASS FRACTIONS
                                         VELOCITY           5225.88 FT/SEC          FUEL            .30847
  PENETRATION HEIGHT    .0203    .0203   AREA               .00072 SQ FT            OXIDIZER        .30847
  SHOCK LOCATION                         HEIGHT AT SHOCK    .0061 FEET              AIR             .38308
    DIST FROM BASE      .098  [illegible] CONC. CRITERION    .79                  ENTHALPY          490.108 BTU/LBM
    DIST FROM JET       .0090    .0090   PSI AT BODY        .0459                 HEAT RELEASE      -.001 BTU/LBM
    BODY STANDOFF       .0059    .0059                                            SP. HEAT RATIO    1.201
                                                                                  SPECIFIC HEAT     .400
                                                                                  MOLEC. WEIGHT     29.709

NOSE RADIUS MULTIPLIER   .7000 (ND)

DOWNSTREAM DISTANCE      .0648 (FT)
STATIONS DOWNSTREAM         6. (ND)

    *** NEWTON  RAPHSON LOOP FAILED, WILL TRY AGAIN***   VOG   .0470
```

Table 4 Flow Field Summary

EXTERNAL BURNING PROPULSION ANALYSIS
BASIC DECK 20 REFERENCE RUN 1 CASE 001

SCHADOW AND CHISEN RESULTS REPORT AFRPL-TR-79-10, APRIL 1979

FLOWFIELD SUMMARY

STATION	ZI IN	RADIUS IN	AREA SQ IN	PRESSURE PSIA	TEMP DEG R	DENSITY LBM/CU FT	VELOCITY FT/SEC	HEAT REL BTU/SEC	ENTHALPY BTU/LBM	GAMMA	MOLEC WGT
3	.193	.892	.103	4.37	1900.79	.006869	5220.88	-.00	498.10	1.201	29.709
4	.399	.804	.146	14.92	1868.27	.021178	2343.25	-.00	409.91	1.257	29.244
5	.518	.818	.159	17.13	1761.07	.026463	2248.07	-.00	364.94	1.271	29.177
6	.677	.838	.179	15.36	1597.84	.026109	2328.16	-.00	307.17	1.284	29.133
7	.837	.851	.194	15.30	1500.27	.027529	2285.46	-.00	276.13	1.295	29.102
8	1.000	.864	.208	14.93	1429.89	.028308	2288.00	-.00	250.21	1.301	29.070
9	1.161	.875	.208	14.99	1434.63	.028349	2288.18	-.00	230.96	1.301	29.080

Table 5 BBLIP Inputs

```
                    EXTERNAL BURNING PROPULSION ANALYSIS                                PAGE 5
            BASIC DECK  20     REFERENCE RUN  1    CASE 601

          SCHADOW AND CHIGIER RESULTS   REPORT AFRPL-TR-79-60, APRIL 1979

     BBLIP INPUTS

    NNOZZ      6.
    PHISD   0.00
    BIGBD   1.00
    CI     0.000
    TYPE       0.
    PRTFLG     0.
    RWF    .5490
    DELTAO  0.00   5.00
    DELTAF  0.00   0.00
    DELINC  0.00   0.00
    THETHO 10.00  10.00
    THETHF  0.00   0.00
    THHINC  0.00   0.00
    DELTAR .0010
    MDOTB 0.0000
    VHATCH  .500
    AOB    0.000
    DELPBI     0.00
    VBI        0.00

      DELPB =     0.00
         VB =     0.00
      RHOOB =0.000000
*** NEWTON  RAPHSON LOOP FAILED, WILL TRY AGAIN***    VO=   .5201
```

Table 6 Solution Variables

ANNULUS 2

SOLUTION VARIABLES
ITERATION 5

ANNULUS	1	2
THETAM	13.450	8.540
DELTA	-.654	3.098
PIPJ	1131.594	2499.273
PIPIN	2463.050	
EPSYSM	-.001834	

Table 7 Performance Summary

EXTERNAL BURNING PROPULSION ANALYSIS
BASIC DECK 20 REFERENCE RUN 1 CASE 601

SCHADOW AND CHIEZE RESULTS REPORT AFRPL-TR-79-60, APRIL 1979

FLOW AT BASE PLANE

JET SHOCK LAYER			
PRESSURE	P1	2190.024	LB/FT**2
MACH NUMBER	M1	1.68	DIMENSIONLESS
VELOCITY	V1	1967.52	FT/SEC
INJECTANT ANNULUS			
PRESSURE	PI	2198.793	LB/FT**2
MACH NUMBER	MI	1.28	DIMENSIONLESS
VELOCITY	VI	[illegible]	FT/SEC

FLOW IMMEDIATELY BEFORE REATTACHMENT

PRESSURE	PB	1131.594	LB/FT**2
MACH NUMBER	MIPS	2.94	DIMENSIONLESS
VELOCITY	VIPS	3361.17	FT/SEC
TEMPERATURE	TCHEM	797.13	DEG R

FLOW AT CRITICAL POINT

PRESSURE	PB	2499.273	LB/FT**2
MACH NUMBER	MIPS	2.17	DIMENSIONLESS
VELOCITY	VIPS	2877.40	FT/SEC
TEMPERATURE	TCHEM	790.77	DEG R

CAVITY GEOMETRY

ANNULUS 1

BASE RADIUS	RB	.12901	FT
ANNULUS THICKNESS AT BASE PLANE	R1	.01098	FT
ANNULUS RADIUS AT TURNING POINT	RTURN	.13570	FT
DISTANCE FROM BASE TO TURNING POINT	LTURN	.01798	FT
ANNULUS RADIUS AT REATTACHMENT	R3	.08899	FT
DISTANCE TO REATTACHMENT	HL	.23573	FT
CAVITY HALF-ANGLE	THETAN	13.490	DEG
ANNULUS STREAMLINE DIVERGENCE	DELTA	-.654	DEG
MIXING MAXIMUM-SLOPE HALF ANGLE	SIGBD	1.000	DEG
GAP WIDTH	GAPW	.0703	FT
GAP WIDTH/BASE CIRCUMFERENCE	GAPWBC	.0371	DIMENSIONLESS
GAP CORRECTION FACTOR	CGAP	.9291	DIMENSIONLESS

ANNULUS 2

ANNULUS RADIUS AT WAKE SHOCK	RTURN	.07764	FT
ANNULUS RADIUS AT CRITICAL POINT	R3	.05091	FT
DISTANCE, REATTACH TO CRITICAL POINT	HL	.38219	FT
INNERFLOW HALF-ANGLE	THETAN	8.548	DEG
ANNULUS STREAMLINE DIVERGENCE	DELTA	3.092	DEG
MIXING MAXIMUM-SLOPE HALF ANGLE	SIGBD	1.000	DEG

Table 7 Performance Summary (continued)

EXTERNAL BURNING PROPULSION ANALYSIS
BASIC DECK 20 REFERENCE RUN 1 CASE 601

SCHADOW AND CHIEZE RESULTS REPORT AFRPL-TR-79-20, APRIL 1979

FLOW RATES			
INJECTANT FLOW			
MASS	MDOTNJ	.0081	LB/SEC
MOMENTUM	MDTJVJ	293.67	LB*FT/SEC**2
BASE BLEED			
MASS	MDOTB	0.00000	LB/SEC
MOMENTUM	MDOTO	0.00	LB*FT/SEC**2
ANNULUS MASS FLOW AT BASE PLANE	MDOTNI	.96179	LB/SEC
ANNULUS 1			
ENTRAINED MASS FLOW			
UPSTREAM OF TURNING POINT	DMDTUP	.0380	LB/SEC
DOWNSTREAM OF TURNING POINT	DMDTDN	.1982	LB/SEC
TOTAL FLOW AT REATTACHMENT			
MASS	MDTIP1	.7988	LB/SEC
MOMENTUM	MTOTAL	2879.46	LB*FT/SEC**2
ANNULUS 2			
ENTRAINED MASS FLOW			
UPSTREAM OF WAKE SHOCK	DMDTUP	.0407	LB/SEC
DOWNSTREAM OF WAKE SHOCK	DMDTDN	.8496	LB/SEC
TOTAL FLOW AT CRITICAL POINT			
MASS	MDTIP1	1.3413	LB/SEC
MOMENTUM	MTOTAL	3659.84	LB*FT/SEC**2
PERFORMANCE			
BASE PRESSURE	PB	1131.994	LB/FT**2
PB/PINF	PBPINF	.98210	DIMENSIONLESS
REATTACHMENT PRESSURE	PIPIN	2483.050	LB/FT**2
PIPIN/PINF	PNPINF	1.24700	DIMENSIONLESS
ADJUSTED BASE PRESSURE	PBA	994.282	LB/FT**2
ADJUSTED PB/PINF	PBPFNA	.90567	DIMENSIONLESS
MASS FLOW RATIO (INJECTED/INTERCEPTED)	MFR1	.0117	DIMENSIONLESS
MASS FLOW RATIO (ROJET*VJET)/(RHOINF*VINF)	MFR2	.6922	DIMENSIONLESS
SPECIFIC IMPULSE GAIN DUE TO BASE PRESSURE RISE	ISPPB	181.602	SECONDS
SPECIFIC IMPULSE LOSS DUE TO NOZZLE CANT	ISPLOS	69.482	SECONDS
SPECIFIC IMPULSE	ISP	121.602	SECONDS

TOTAL TIMES VMAX EXCEEDED 0
TOTAL TIMES LOW TCHEM ENCOUNTERED 0

5.2 Intermediate Level Output

5.2.1 Station Output

This level output is produced upstream of the base and is obtained by setting flag PF_A equal to 1. It includes all output contained in Level 1 plus additional tables of expanded information of station data. The tables appear for each station in the downstream region to the base plane.

The downstream station summary is shown in Table 8. It includes station location, current summary flow field data, and a station flow field for the computational ray measured from the body normal to the shock. This flow field contains for each point along the ray, its Z-distance and radius measured in penetration heights, velocity normalized to freestream velocity, pressure, density normalized to freestream density, local velocity, temperature, stream function (PSI) value, and a measure of constant enthalpy at the PSI value. The first flow field line of output is on the shock, and the last is at the body. The force computations indicated in the upper left corner are deleted.

5.2.2 Annulus Output

This level of output is produced at and downstream of the base plane and is obtained by setting PF_p equal to 1. Table 9 lists flow parameters and geometry at the base when computations are entered for annulus 1 and conditions of the annulus 2 entrance when computations are entered for the 2nd annulus.

For annulus 1, AI, PI, MI, VI, MDOTI, MOMI, and FI denote the area, pressure, Mach number, velocity, mass flow rate, momentum and force, respectively, of the annulus flow from each nozzle at the base plane. The PIP1 and MDTIP1 are pressure and flow rate at reattachment and are initialized to the values at the base. The MOLWT, ROCHEM, TCHEM, and GAMMA denote molecular weight, density, temperature and specific heat from thermochemistry. The outer flow parameters are indicated by M1, P1, T1, RHO1, V1, M1P, P1P, RHO1P, and V1P, with the P- appended variables representing a Prandtl-Meyer expansion of flow around the base. The MDOTNI, MODTNA and MDOTNJ are the total mass, air and jet flow rates from the nozzles around the base cavity. The mass fractions of fuel and oxidizer are XMF and XMO. The AREAB, RB and RI denote the base area, base radius and annulus thickness at the base plane.

Table 8 Downstream Station Summary

EXTERNAL BURNING PROPULSION ANALYSIS

BASIC DECK 20   REFERENCE RUN 1   CASE 601

SCHADOW AND CHIESE RESULTS   REPORT AFRPL-TR-79-10, APRIL 1979

DOWNSTREAM STATION 9 SUMMARY

Z = .104 FEET

OUTER	0.000 LBS	PRESSURE	2198.79 PSF	TOTAL HEAT RELEASE	-.009 BTU/SEC
INNER	0.000 LBS	TEMPERATURE	1434.63 DEG R	STA HEAT RELEASE	-.000 BTU/SEC
TOTAL	0.000 LBS	DENSITY	.028349 LBM/CU FT	ENTHALPY	330.964 BTU/LBM
BASE	0.000 LBS	VELOCITY	2285.16 FT/SEC	SP. HEAT RATIO	1.301
TOTAL FORCE	0.000 LBS	AREA	.0014 SQ FT	MOLECULAR WEIGHT	29.080

*** STATION 9 FLOWFIELD ***

	Z/H	R/H	U	P,PSF	RHO/RDINF	VEL,FT/SEC	TEMP,R	PSI	S
17	.3783E+01	.3775E+01	.8484E+00	.2340E+04	.1141E+01	.1919E+04	.5696E+03	.7204E+01	.1786E+00
16	.3968E+01	.3488E+01	.8926E+00	.2302E+04	.1128E+01	.2034E+04	.5670E+03	.6014E+01	.1787E+00
15	.4029E+01	.3393E+01	.8938E+00	.2291E+04	.1124E+01	.2036E+04	.5662E+03	.5643E+01	.1787E+00
14	.4092E+01	.3296E+01	.8948E+00	.2279E+04	.1120E+01	.2039E+04	.5654E+03	.5271E+01	.1787E+00
13	.4157E+01	.3195E+01	.8959E+00	.2267E+04	.1115E+01	.2041E+04	.5646E+03	.4898E+01	.1787E+00
12	.4224E+01	.3091E+01	.8968E+00	.2255E+04	.1111E+01	.2043E+04	.5639E+03	.4526E+01	.1788E+00
11	.4293E+01	.2984E+01	.8978E+00	.2243E+04	.1107E+01	.2045E+04	.5631E+03	.4154E+01	.1788E+00
10	.4365E+01	.2873E+01	.8987E+00	.2231E+04	.1102E+01	.2047E+04	.5624E+03	.3781E+01	.1789E+00
9	.4440E+01	.2757E+01	.8995E+00	.2220E+04	.1098E+01	.2049E+04	.5618E+03	.3409E+01	.1790E+00
8	.4518E+01	.2636E+01	.9003E+00	.2208E+04	.1093E+01	.2051E+04	.5611E+03	.3037E+01	.1791E+00
7	.4599E+01	.2509E+01	.9002E+00	.2196E+04	.1087E+01	.2051E+04	.5612E+03	.2664E+01	.1798E+00
6	.4685E+01	.2375E+01	.8997E+00	.2184E+04	.1080E+01	.2050E+04	.5616E+03	.2292E+01	.1801E+00
5	.4777E+01	.2234E+01	.8979E+00	.2172E+04	.1071E+01	.2049E+04	.5633E+03	.1920E+01	.1812E+00
4	.4874E+01	.2083E+01	.8919E+00	.2160E+04	.1057E+01	.2032E+04	.5677E+03	.1547E+01	.1836E+00
3	.4979E+01	.1920E+01	.8843E+00	.2148E+04	.1043E+01	.2019E+04	.5720E+03	.1175E+01	.1859E+00
2	.5094E+01	.1741E+01	.8869E+00	.2137E+04	.1038E+01	.2020E+04	.5718E+03	.8027E+00	.1862E+00
1	.5222E+01	.1495E+01	.8784E+00	.2100E+04	.1030E+01	.1988E+04	.5829E+03	.4304E+00	.1878E+00

Table 9 Base End Conditions

ANNJLUS 1

BASE END CONDITIONS

AI	.14442761E-02	PI	.21587935E+04	RI	.18794551E+01	VI	.28051821E+04	MDOTI	.29100996E-02
PIP1	.21587935E+04	MDTIP1	.29100996E-02	MOLWT	.29079619E+02	ROCHEM	.88110148E-03	TOHEM	.14346335E+04
GAMMA	.13005078E+01	M1	.16832407E+01	R1	.21600237E+04	T1	.58251783E+03	MDOTNI	.17460598E-01
MDOTNA	.16431609E+01	MDOTNJ	.27893489E-02	XMP	.13696744E-02	XMO	.13696744E-02	AREAB	.49091856E-01
RB	.12500569E+00	R1	.10884821E-01	AYN	.34279943E-01	RHO1	.21623338E-02	V1	.19876213E+04
MOMI	.39900649E+02	M1P	.16832407E+01	P1P	.21600237E+04	V1P	.19876213E+04	RHO1P	.21623338E-02
THETAB	.38849181E+01	THETAW	.99999997E+01	THETSO	.99999997E-02	MVRINL	-.10963976E-01	P1	.18707363E+02

*** NEWTON RAPHSON LOOP FAILED, WILL TRY AGAIN*** VCO .9201

AIN measures the cross sectional area between the base and reattachment circumferences. The angles THETAB and THETAW are the body angles measured with respect to the vehicle surface and the cavity half angle. THETAC is the input angle THETA2 discussed in the section "EBPA Inputs". MVRINL is to be ignored.

At the entrance to annulus 2, AI, PI, MI, VI, MDOTI, MOMI and FI are updated to contain the values at reattachment. MOLWT, ROCHEM, TCHEM and GAMMA are initially the last results computed in annulus 1. M1, P1, T1, RHO1, V1, M1P, P1P, RHO1P, and V1P become the outer flow parameters for annulus 2. MDOTNI is also updated. MDOTNA, MDOTNJ, XMF and XMO remain constant throughout iterations. AREAB, RB, RI and THETAB become values at the reattachment cross sectional entrance to annulus 2. AIN is the initial value of the cross sectional area between the circumferences at reattachment and the critical point. The THETAW is the inner flow half-angle and THETAC contains the current value of the cavity half-angle of annulus 1.

All of the above tabulations are printed, if requested, for each new computation of the streamline divergence angle of annulus 1 and at the entrance of computations for annulus 2.

Tables 10 and 11 are samples of compact iteration output for annulus 1 and annulus 2 respectively.

The output for annulus 1 is printed at convergence of the base pressure from iterations of the streamline divergence angle DELTA and at the current iterated cavity half angle THETAW. For this option, STEP is the number of iterations in DELTA required for convergence. R3 is the annulus radius at reattachment, AL and HL distances from the base center and along the centerline to reattachment. LTURN is the distance to and RTURN the annulus radius at the turning point. TURANG is the turning angle of flow. ALPHA is the angle between an equivalent single ray and streamline upstream. DAREA is the area for mass flow entrained in the outer sheet layer. PIP1 is the converged base pressure at reattachment. POUTU, POUTD and PIN are pressures on the annulus outer --upstream and downstream of the turning point-- and inner

Table 10 Annulus 1 ($PF_p = 1$)

ANNULUS 1

PAGE 2 A

STEP	DELTA PTP1 MDTIP1 M2 MVREX	THETAW POUTU DMTOTA F2 PARIN	M3 POUTD TOTMOM V2 RHOMCK	THETWO PIN DMOMI RHO2 ROCHEM	EPSG PIPR DMDTUP RHOVUP MDTENT	AL PINE DMDTDN RHOVDN HREAT	ML EPSP MIP1 VOUTUP RSTAR	LTURN PHI TCHEM VOUTDN HLREL	RTURN AIP1 PDREL PARDU	TURANG FIN VIP1 MVRDU	ALPHA FOUT VMAX PAROD	DAREA FTOTAL RCHEM MVROD
3	-.246	10.000	.088844	0.000	0.000000	.7199	.3199	.01891	.13907	10.256	39.115	.004759
	1406.201	2199.347	1405.665	1983.048	1369.171	1606.959	-.000381	1.601	.00890	40.209	-29.750	100.634
	.02836	.01090	.77	23.57	.00102	.00983	2.286	799.40	-.000079	3110.02	3610.51	1714.94
	2.044	1240.967	2220.72	.0014854	4.8973	3.4699	1987.78	2180.08	29.20	-.0024	299.40	3.0324
	-16.15	-273.40	.067062	.0010252	0.000000	0.0000	0.00000	0.000000				

Table 11 Annulus 2 ($PF_p = 1$)

ANNULUS 2

STEP	DELTA PIP1 MDTIP1 M2 MVREX	THETAW POUTU DMTOTA P2 PARIN	R3 POUTD TOTMOM V2 RHOMCK	THETWG PIN DMOM1 RHO2 ROCHEM	SPSG PIPH DMDTUP RHOVUP MDTENT	AL PINE DMDTDN RHOVDN MREAT	ML SPSP MIP1 VOUTUP RSTAR	LTURN PHI TOHEM VOUTDN MLREL	RTURN AIP1 PDREL PAROU	TURANG FIN VIP1 MVROU	ALPHA FOUT VMAX PAROD	DAREA FTOTAL ROHEM MVROD
3	4.412	10.000	.050188	8.853	-.144667	.4810	.3784	.03808	.07744	-8.284	29.896	.003500
	2498.808	1396.615	2494.026	1700.868	1410.079	3441.263	-.001019	8.400	.00748	38.330	-83.037	139.794
	.04131	.01768	.89	38.28	.00133	.01835	2.108	749.03	.000070	8892.97	3332.16	1716.47
	1.668	2210.182	2206.20	.0037959	3.8127	8.7681	2449.28	2143.04	26.76	.7775	339.14	3.4111
	-16.21	-263.09	.198139	.0019073	.001226	.0219	.01171	.000439				
4	3.036	8.593	.050561	8.483	-.000186	.4881	.3818	.03681	.07779	-8.384	84.650	.003600
	2492.748	1394.311	2493.970	1848.173	1841.499	3879.891	.000901	8.348	.00760	35.334	-88.931	138.938
	.04162	.01778	.90	38.03	.00127	.01871	2.174	781.98	-.000389	8879.34	3324.38	1716.52
	1.668	2211.373	2208.89	.0037973	3.8093	8.7668	2449.97	2143.28	89.67	.7491	341.88	3.4438
	-14.68	-237.79	.218891	.0019811	.001215	.0317	.01169	-.000174				

boundaries. PIPM and PMI are the pressure and Mach number obtained after the flow is turned at the base plane. EPSP is the relative error between PIP1 and POUTD and satisfies the criterion for convergence. AIP1 is the cross sectional area of the flow at reattachment. FIN, FOUT, and FTOTAL are inner, outer, and total forces; MDTIP1 is mass flowrate at reattachment, DMTOTA is the amount of added air, TOTMOM is conservation momentum, and DMOMI is the change in mass flow up and downstream of the turn in flow. DMDTUP and DMDTDN are the mass flow rates. MIP1, TCHEM, VIP1, VMAX, RCHEM and ROCHEM are reattachment Mach number, temperature, velocities, perfect gas law constant, and density of the flow. M2, P2, V2, and RHO2 are the outer flow parameters at reattachment. RHOVUP, RHOVDN, VOUTUP, and VOUTDN are the ρV products and velocities up- and downstream of the turning point. PDREL gives a relative error for successive iterates in PIP1. THETWG, EPSG, RSTAR, HLREL, which have no meaning for annulus 1, MDTENT and MREAT, not computed at this point, are all set to zero. The variables PINR, PAROU, MUROU, PAROD, MVREX, PARIN and RMOMCK are irrelevant.

In annulus 2, the output is printed at each convergence of pressure at the critical point, and until there is convergence in the inner flow half angle. The variables are similarly defined as in annulus 1. Those values defined relative to the base plane in annulus 1 are now defined relative to the cross sectional entrance to annulus 2; and the values defined at reattachment are now defined at the critical point. THETAW and THETWG are the inner flow half angle iterates. The EPSG is the relative error satisfying angle convergence. MDTENT and MREAT are entrained mass flow rate and Mach number of the inner flow at reattachment. RSTAR is the annulus thickness at the critical point. HLREL gives a relative error for successive iterates in HL.

Table 12 lists computations for the 1st annulus inner flow at reattachment. If $PF_p = 1$, the output is printed on convergence of the divergence angle DELTA at the current cavity half-angle THETAW. If $PF_p = 2$, output is printed at each DELTA iteration. The first line of values are reprinted from Table 10. UOXR is centerline flow velocity of the recirculation region, positive downstream. RCAV is annulus inner flow radius, XMDTSL and MDTDSL are the incremental and total momentum flux across the dividing streamline.

Table 12 Inner Flow

ANNULUS 1

PAGE 3 A

INNER FLOW AT REATTACHMENT

DELTA	THETAW	ML	PIPE	VIP1	MIP1	TCHEM	RCHEM	RDCHEM
-.2496	10.0000	.3197	1456.2018	3110.9978	2.2863	770.4282	1716.9449	.0210283

I	MLX	UOXR	RCAV	XMDTBC	MDTDBL
1	.0639	-1912.9906	.1137	6.7939	6.7939
2	.1279	-1533.6425	.1025	6.1387	12.9326
3	.1918	-1559.6227	.0912	5.4844	18.4170
4	.2558	-1503.2390	.0799	4.9112	23.3282
5	.3197	-1439.2509	.0686	4.2992	27.6274

PIP1N	MDTDBL	BDOTG	MDOTHC	MDTENT	MRBAT
3273.4345	27.6274	0.0000	0.0000	.000703	.0331

MRB
0.0000

These values are tabulated at distances HLX along the centerline from the base plane to reattachment. PIP1N is the pressure at reattachment, MDOTO base bleed momentum, MDOTHL momentum flux out of the inner flow at the downstream end, MDTENT entrained mass flow rate, MRE and MREAT the reattachment Mach numbers averaged over the exit flow of annulus 1 and the entrance flow to annulus 2, respectively.

5.3 Detail Level Output

5.3.1 Diagnostic/Trace Output

This level of output is called by setting PF_A equal to 2. This level of output includes all the printout of the other two levels plus the intermediate computations of variables and arrays during the interaction processes for the conservation equations in the upstream, downstream, and annulus regions, the thermochemical computations, mixing calculations, and calculations for the beginning of the downstream region. This level of output is primarily for debugging and maintenance operations and examples are not included in this manual because of the large quantity of output.

5.3.2 Chemistry Data Printout

Additional chemistry data may be obtained for each station by setting PF_B equal to 1. The output consists of the chemical composition of products for each combustion zone at each upstream, downstream, and annulus station.

5.3.3 Extended Annulus Output

This output is an extension of the iteration output discussed in the section "Annulus Output" and is obtained by setting PF_P equal to 2. A sample of the output is shown in Tables 13 and 14. In annulus 1, the STEP value in this option identifies a computation step. STEP 0 is a first computation for a given THETAW and DELTA. The 1 and 2 STEP's are generated to update thermochemistry to be consistent with the PIP1. In annulus 2, the above looping is repeated to achieve a consistent HL as reflected in the value HLREL. All other variables have the meanings described in the section "Annulus Output."

5.4 Sample Case Loadsheet

Figures 9, 10 and 11 represent loadsheet data entries to produce the sample case run.

Table 13 Annulus 1 ($PF_p = 2$)

ANNULUS 1

PAGE 8 A

STEP	DELTA	THETAW	R3	THETWO	EPSO	AL	HL	LTURN	RTURN	TURANG	ALPHA	DAREA
	PIP1	POUTU	POUTO	PIN	PIPN	PINR	EPSP	PHI	AIP1	PIN	POUT	PTOTAL
	MDTIP1	DMTOTA	TOTMOM	DMOMI	DMDTUP	DMDTDN	MIP1	TOMEM	PDREL	VIP1	VMAX	ROMEM
	M2	P2	V2	RHO2	RHOVUP	RHOVDN	VOUTUP	VOUTDN	PAROU	MVROU	PAROD	MVROD
	MVREX	PARIN	RHOMCK	ROCHEM	MDTENT	MREAT	RETAR	HLREL				
WAKE ANGLE 1												
0	-.246	10.000	.086844	0.000	0.000000	.7190	.3197	.01571	.13587	10.256	39.119	.004788
	1290.450	2159.347	1409.665	1983.042	1369.171	1026.999	.007263	1.601	.00890	48.207	-27.750	100.634
	.02836	.01090	.78	23.57	.00102	.00988	2.469	742.89	0.000000	3241.13	3628.00	1714.07
	2.044	1240.967	8229.72	.0014554	4.2973	3.4699	1987.78	2180.82	29.30	-.0004	299.40	3.0324
	-16.18	-273.40	[illegible]	[illegible]	0.000000	0.0000	0.00000	0.000000				
SOLUTION TEMPERATURE LOOPS												
1	-.246	10.000	.086844	0.000	0.000000	.7190	.3197	.01571	.13587	10.256	39.119	.004788
	1406.312	2159.347	1405.665	1983.042	1369.171	1026.999	-.000390	1.601	.00890	48.207	-27.750	100.634
	.02836	.01090	.77	23.57	.00102	.00988	2.286	799.99	.000784	3110.71	3610.51	1714.04
	2.044	1240.967	8229.72	.0014554	4.2973	3.4699	1987.78	2180.82	29.30	-.0004	299.40	3.0324
	-16.15	-273.40	.069082	.0010291	0.000000	0.0000	0.00000	0.000000				
2	-.246	10.000	.086844	0.000	0.000000	.7190	.3197	.01571	.13587	10.256	39.119	.004788
	1406.201	2159.347	1405.665	1983.042	1369.171	1026.999	-.000381	1.601	.00890	48.207	-27.750	100.634
	.02836	.01090	.77	23.57	.00102	.00988	2.286	799.40	-.000079	3110.88	3610.51	1714.04
	2.044	1240.967	8229.72	.0014554	4.2973	3.4699	1987.78	2180.82	29.30	-.0004	299.40	3.0324
	-16.15	-273.40	.069082	.0010252	0.000000	0.0000	0.00000	0.000000				

* ITERATIONS FOR DELTA 3 *

Table 14 Annulus 2 ($PF_p = 2$)

ANNULUS 2

STEP	DELTA PIF1 MDTIP1 M2 MVHEX	THETAW PDUTU DMTOTA P2 PAMIN	XS PDUTO TOTMDM V2 RMOMCK	THETAG PIN DMDTI RHO2 ROCHEM	EPSG PIPM DMDTUP RHOVUP MDTENT	AL PINR DMDTDN RHOVDN MREAT	ML EPSP MIP1 VOUTUP RSTAR	LTURN PM1 TCHEM VOUTDN MLREL	RTURN AIP1 PDREL PAROU	TURANG FIN VIP1 MVRDU	ALPHA FOUT VMAX PARDU	DARGA FTOTAL RCHEM MVRDD
AKE ANGLE 2												
0	3.036	8.553	.050485	8.459	-.011082	.4681	.3828	.03651	.07779	-8.324	26.650	.003609
	2427.825	1364.311	2454.349	1843.128	1541.499	3868.011	.010925	2.345	.00758	36.325	-22.994	138.523
	.04164	.01801	.90	38.97	.00127	.01673	2.201	742.46	0.000000	2897.34	3321.35	1716.54
	1.668	2211.393	2203.89	.0037973	3.8093	8.7674	2445.97	2143.16	25.67	.7451	342.65	3.4480
	-14.78	-239.01	.213395	.0019271	.001240	.0318	.01170	-.011051				
SOLUTION TEMPERATURE LOOPS												
1	3.036	8.553	.050485	8.459	-.011082	.4681	.3828	.03651	.07779	-8.324	26.650	.003609
	2457.886	1364.311	2454.349	1843.128	1541.499	3868.011	-.001439	2.345	.00758	36.325	-22.994	138.523
	.04164	.01801	.90	38.97	.00127	.01673	2.179	750.23	.012382	2882.64	3323.83	1716.53
	1.668	2211.393	2203.69	.0037973	3.8093	8.7674	2445.97	2143.16	25.67	.7451	342.65	3.4480
	-14.78	-239.01	.213395	.0019058	.001240	.0318	.01170	-.011051				
2	3.036	8.553	.050485	8.459	-.011082	.4681	.3828	.03651	.07779	-8.324	26.650	.003609
	2457.278	1364.311	2454.349	1843.128	1541.499	3868.011	-.001192	2.345	.00758	36.325	-22.994	138.523
	.04164	.01801	.90	38.97	.00127	.01673	2.179	750.08	-.000248	2883.00	3323.83	1716.53
	1.668	2211.393	2203.89	.0037973	3.8093	8.7674	2445.97	2143.16	25.67	.7451	342.65	3.4480
	-14.78	-239.01	.213395	.0019082	.001240	.0318	.01170	-.011051				
AKE ANGLE 2												
0	3.036	8.553	.050555	8.481	-.008493	.4681	.3819	.03651	.07779	-8.324	26.650	.003601
	2446.389	1364.311	2454.000	1843.162	1541.499	3878.378	.003111	2.345	.00760	36.323	-22.936	138.536
	.04162	.01798	.90	38.93	.00127	.01671	2.180	750.06	0.000000	2883.03	3323.83	1716.53
	1.668	2211.393	2203.89	.0037973	3.8093	8.7668	2445.97	2143.24	25.67	.7451	341.91	3.4439
	-14.70	-237.91	.214898	.0019083	.001220	.0317	.01168	-.002311				
SOLUTION TEMPERATURE LOOPS												
1	3.036	8.553	.050555	8.481	-.008493	.4681	.3819	.03651	.07779	-8.324	26.650	.003601
	2453.225	1364.311	2454.000	1843.162	1541.499	3878.378	.000316	2.345	.00760	36.323	-22.936	138.536
	.04162	.01798	.90	38.93	.00127	.01671	2.174	751.83	.002794	2879.62	3324.35	1716.52
	1.668	2211.393	2203.89	.0037973	3.8093	8.7668	2445.97	2143.24	25.67	.7451	341.91	3.4439
	-14.70	-237.91	.214898	.0019019	.001220	.0317	.01168	-.002311				
2	3.036	8.553	.050555	8.481	-.008493	.4681	.3819	.03651	.07779	-8.324	26.650	.003601
	2453.394	1364.311	2454.000	1843.162	1541.499	3878.378	.000247	2.345	.00760	36.323	-22.936	138.536
	.04162	.01798	.90	38.93	.00127	.01671	2.174	751.88	.000069	2879.53	3324.35	1716.52
	1.668	2211.393	2203.89	.0037973	3.8093	8.7668	2445.97	2143.24	25.67	.7451	341.91	3.4439
	-14.70	-237.91	.214898	.0019014	.001220	.0317	.01168	-.002311				

EXTERNAL BURNING PROPULSION ANALYSIS

LOADSHEET 1

MUST BE FILLED IN FOR PROPER PROCESSING

BD	RR	CASE	PART CASE
002	03	003	

JOB TITLE CARD

1	E0075 SCHADOW AND CHIEZE RESULTS REPORT AFRPL-TR-79
2	E0073-10, APRIL 1974

E KEYPUNCH: PUNCH IN ALL CARDS

QUAN	LOC	VALUE	
VEHICLE PARAMETERS			
θ_1	1	12.	DEG
θ_2	2	.01	DEG
X_{body}	3	5.584	FT
X_{cone}	4	0.584	FT
D_L	30		
θ_j	65	0.	DEG
R_E	66		FT
R_N	67		FT
FLIGHT PARAMETERS			
M_∞	5	2.	
ALT	6		FT
P_∞	7	1944.	PSF
T_∞	8	540.	°R
α	9		DEG
PHI	10		DEG
I_{CG}	11	1.83	FT
γ	12	1.4	
INJECTOR PARAMETERS			
P_j	13	87.7	PSI
A_j	14	.02090	IN^2
E_{RATIO}	15	1.01	
α_j	16	0.	DEG
Z_{JET}	17	1.	IN
β	18	15.	DEG

QUAN	LOC	VALUE	
CHEMISTRY PARAMETERS			
KINDF	19	7.	
KINDO	20	9.	
η_R	21	0.	
C_{crit}	29	.94	
N_Z	32	1.	
O/F	64	1.	
LOCAL CONDITIONS			
M_L	24		
P_L	25		PSF
T_L	26		°R
V_L	27		FT/SEC
OPTION FLAGS			
PF_A	39		
PF_B	40		
P_C	50		
LC	68		

[illegible]	22	.7

Figure 9 Sample Case Loadsheet BD Entries

EXTERNAL BURNING PROPULSION ANALYSIS

LOADSHEET 2

E KEYPUNCH: PUNCH IN ALL CARDS

MUST BE FILLED IN FOR PROPER PROCESSING

BD	RR	CASE	PART CASE
[illegible]	01	003	

QUAN	LOC	VALUE
BASE GEOMETRY		
N_{NOZZ}	96	6.
Φ_B	97	
σ_B	98	1.
C_B	99	
RW_f	102	
ANNULUS GEOMETRY		
δ_{o_1}	103	0.
δ_{f_1}	105	
δ_{Δ_1}	107	
$\theta_{w_{o_1}}$	109	10.
$\theta_{w_{f_1}}$	111	
$\theta_{w_{\Delta_1}}$	113	
δ_{o_2}	104	5.
δ_{f_2}	106	
δ_{Δ_2}	108	
$\theta_{w_{o_2}}$	110	10.
$\theta_{w_{f_2}}$	112	
$\theta_{w_{\Delta_2}}$	114	

QUAN	LOC	VALUE
BASE BLEED PARAMETERS		
ΔR	115	.001
$\dot{m}_B$	116	0.
V_M	117	.5
A_{oB}	118	0.
ΔP_B	119	0.
V_B	120	0.
PRINT FLAG		
PF_P	101	0.

KEYPUNCH: INPUT A-2

Figure 10 Sample Case Loadsheet RR Entries

EXTERNAL BURNING PROPULSION ANALYSIS

LOADSHEET 1

MUST BE FILLED IN FOR PROPER PROCESSING

63–65 BD	66–67 RR	68–70 CASE	71–72 PART CASE
020	01	601	

JOB TITLE CARD

Card (cc 1–5)
E0075
E00[illegible]3

E KEYPUNCH:
PUNCH IN ALL CARDS

QUAN	LOC	VALUE	
VEHICLE PARAMETERS			
θ_1	1		DEG
θ_2	2		DEG
X_{body}	3		FT
X_{cone}	4		FT
D_{N1}	30		
θ_j	65		DEG
R_E	66		FT
R_N	67		FT
FLIGHT PARAMETERS			
M_∞	5		
ALT	6		FT
P_∞	7		PSF
T_∞	8		°R
α	9		DEG
PHI	10		DEG
I_{CG}	11		FT
γ	12		
INJECTOR PARAMETERS			
P_j	13	51.7	PSI
A_j	14	.02097	IN^2
E_{RATIO}	15		
α_j	16		DEG
Z_{JET}	17		IN
β	18		DEG

QUAN	LOC	VALUE	
CHEMISTRY PARAMETERS			
KINDF	19		
KINDO	20		
η_R	21		
C_{crit}	29		
N_Z	32		
O/F	64		
LOCAL CONDITIONS			
M_L	24		
P_L	25		PSF
T_L	26		°R
V_L	27		FT/SEC
OPTION FLAGS			
PF_A	39		
PF_B	40		
P_c	50		
LC	68		
P_T/T_T	22		

Figure 11 Sample Case Loadsheet CASE Entries

Section 6

OPERATING MESSAGES

This section lists messages that are for the user's information. The messages indicate that although the program terminates in normal fashion, the expected results have been influenced by corrective actions within the program. The messages are listed under the name of the subroutine in which they occur.

<u>Subroutine AMTURN</u>

AMTURN NON-CONVERGENT IN 20 ITERATIONS

Local conditions computed for biconic vehicle may be in error, or Mach expansion angle in the annulus region is excessive. Program continues execution.

<u>Subroutine BBMODL</u>

1. SOLUTION NOT FOUND FOR THETAW n
2. SOLUTION NOT FOUND FOR DELTA n.

   The maximum number of iterations for the half angles or the divergence angles in the annulus region has occurred. The n is the annulus number. The program continues execution until the message occurs for the THETAW 1. At that point, execution proceeds to the control routine for a new case of input data.

<u>Subroutine GEMTRY</u>

1. ***HL = XXX LTURN = XXX AT DELTA = XXX AND THETAW = XXX***

   TRY NEXT DELTA

   The distance HL to the reattachment (or critical point) is less than the distance LTURN from the base (or reattachment) to the turning point for annulus 1 (or 2). Program will adjust values and continue execution.
2. INITIAL THETAW TOO LARGE - TRY NEW GUESS

   The cavity half angle of annulus 1 will be reduced and execution continued.
3. ***TRY NEW THETAW THETAW DELTA R3 RTURN HL L TURN RSTAR AIP1

   XXX XXX XXX XXX XXX XXX XXX XXX

   The current cavity half-angle of either annulus has caused the annulus radius and/or cross section area at reattachment or critical points to

become negative. The XXX's represent the values listed. The program will continue execution.

SUBROUTINE INCRMT

1. *** DELTA RESET FROM XXXX
2. *** THETAW RESET FROM XXXX

The Newton-Raphson method has produced an increment of undesirable magnitude. The value is reset from that indicated and execution continues. The message(s) are printed only if t'e PF_p flag of Loadsheet 2 is set equal to 2.

Subroutine OUTER

1. MAXIMUM ITERATIONS IN OUTER
AT DOWNSTREAM STATION XXX
SUMMARY PRINTOUTS FOLLOW

Inner and outer solutions upstream of the base have not converged. Summary printouts and totals will be printed up to the indicated station and execution will proceed to the next data case.

2. PRESSURE PERTURBATIONS BECOME INSIGNIFICANT
AT DOWNSTREAM STATION XXX
SUMMARY PRINTOUTS FOLLOW

Expansion process is such that flow Mach angle has been achieved and no further expansion can occur. Summaries and totals are printed and the program execution proceeds to the next data case.

Subroutine PBSOLV

*** MAX LOOPS FOR HLREL XXXX - WILL TRY NEW DATA

This message applies to the annulus 2 region and indicates inner loop iterations have not produced a satisfactory computation for the reattachment to critical point distance. Execution continues with the existing value of HL.

Subroutine PMOMNT

***TCHEM = XXXX - TRY NEXT DELTA

Temperature computations in the annulus region have fallen below that permitted by the program. A new divergence angle is determined and execution continues. The message is printed only when $PF_p = 2$.

Section 7

TROUBLESHOOTING

This section provides information necessary for the user to troubleshoot the subprograms to the degree needed to isolate and correct user errors. All diagnostic messages and their explanations are listed under the name of the subroutine in which they are printed.

Subroutine DEFIOJ

CANT FIND BASIS
FATAL ERROR IN H099, EXECUTION TERMINATED

An improper chemistry tape has been mounted. Check for correct reel number. Program terminates execution.

Subroutine DNCON

1. NEWTON RAPHSON LOOP FAILED, WILL TRY AGAIN VC=XXX.XXXX

   Program is attempting to estimate velocity in downstream region. The message is information only and the program continues.
2. EST VIP1 CONVG FAIL, VG, VC, VCDR, VIP1, VMAX, CONV

   (Printed values for each variable)

   Program is attempting to estimate for velocity in downstream region. A new guess is made and the program continues.
3. ROCHEM CONVG FAILURE, ROCHEM, ROBB, VIP1, VIP1C

   (Printed values for each variable)

   Convergence failure in computation of velocity from continuity. A new guess is made and the program continues.
4. OVER 40 ITERATIONS IN DOWNSTREAM

   Iteration with chemistry to solve conservation equations in density, velocity and pressure have exceeded 40. Program proceeds to next data case.
5. CHOKED FLOW

   No solution exists at this point of downstream iteration. Program assumes sonic flow and continues.

Subroutine MIX

MIX WILL NOT CONVERGE

Output from routine unobtainable in 30 iterations. Program requires modification for rectification. Discard data. Program will proceed to next case of data.

Subroutine PERFRM

FATAL ERROR IN PERFRM

Message follows indication of error in fuel ingredient table. Program proceeds to next case.

Subroutine SEARCH

HARK, NO COMBUSTION SPECIES FOR (NAME) REVISE PEPAUX

Combustion species indicated could not be found on the chemistry input tape. Program proceeds to next case.

Subroutine SIBODY

1. THIS NOTE IS FROM THE RADIUS SUBPROGRAM, AND INDICATES THE EXISTENCE OF AN ERROR CONDITION

   Applies to the following messages:

2. THIS SUBROUTINE CONCLUDES THAT THE SOLUTION RAIR IS LESS (GREATER) THAN THE MINIMUM (MAXIMUM) PERMISSIBLE VALUE OF RMIN (RMAX). THE MINIMUM (MAXIMUM) PERMISSIBLE VALUE WILL BE RETURNED AS THE SOLUTION VALUE.

   Information message in the computation of ψ values at the body. RAIR is radius of curvature parameter.

Subroutine STREAF

1. BODY STREAMLINE ABOVE JET SHOCK
2. STREAMLINE INTERSECTS SHOCK BEYOND Z=1

   For either message there is no solution for outer conditions with given inner conditions. Program proceeds to next data case.

Subroutine UPCON

1. VI CONVERGENCE INCOMPLETE

   Information only. The Newton-Raphson solution for upstream velocity has not been achieved. A new guess is made and another solution is attempted.

2. CHOKE FLOW

No solution exists at this point of upstream iterations. Program assumes sonic flow and continues.

Subroutine INPUTA

The following error messages will be printed if any of these conditions occur when input data cards are loaded.

1. CARD IGNORED

   Printout of card; execution will continue

   Either card column 1 contains a zero or blank, or card column 62 contains any punch other than a zero or blank.

   If any one of the following errors occur, these error messages will be printed, and execution will be terminated.

2. PROGRAM NUMBER ON DATA CARD INCONSISTENT WITH ACTUAL PROGRAM NUMBER XXXX

   Printout of card

   The program number has been punched in the data cards, and it does not agree exactly with the program number referenced in the CALL INPUTA statement. Leave columns 73 - 76 blank.

3. INVALID CARD COLUMN 1 PUNCH

   Printout of card

   Column 1 contains a punch other than zero, blank, 5, 6, 7, D, E, I, N, or =. EBPA data cards require the E or =.

4. INCORRECT CASE IDENTIFICATION FIRST CARD

   Printout of card

   First card contains either a non-zero RR and a non-zero CASE, or a zero RR and a zero CASE.

5. CARDS NOT IN SEQUENCE.

   Printout of card

   RR or CASE numbers on data cards are not in monotonically increasing order.

6. REFERENCE RUN NUMBER CHANGE BEFORE NONZERO CASE.

   Printout of card

   RR number has changed before a CASE data card has been read.

8. NO CASE DATA

   Printout of card.

   All data cards were read, without encountering a non-zero CASE number.

9. LOCATION LESS THAN OR EQUAL TO ZERO

   Printout of card

   LOC entry on a data card was ≤ 0.

10. LOCATION GREATER THAN MAXD - XXXXX.

    Printout of card

    LOC entry on data card is greater than maximum size specified in the CALL INPUTA statement.

11. MAXD LESS THAN 4.

    Maximum size specified in the CALL INPUTA statement is <4.

12. BASIC DECK NUMBER CHANGE BEFORE NON-ZERO CASE.

    Printout of card.

    BD number has changed before a CASE data card has been read.

13. NO BASIC DECK DATA

    Printout or card

    BD number had changed, and a non-zero CASE number appears on the same card.

If any of the following messages occur, the user should check card column 1 for an "E" on numeric data cards and for an "=" on title heading cards:

PART CASE PREVIOUSLY DEFINED FOR MATRIX INPUT

PART CASE PREVIOUSLY DEFINED FOR NON-MATRIX INPUT

DIMENSIONS OF MATRIX HAVE NOT BEEN DEFINED

NUMBER OF ROWS OR COLUMNS LESS THAN OR EQUAL TO ZERO

ROW OR COLUMN INDEX IS ZERO

MAXIMUM DIMENSIONS OF MATRIX (XXXX.XXXX) EXCEEDED.

Subroutine INPUT

1. BD = XXX, RR = XX, CASE = XXX, PC = XX

   DATA ARRAY SIZE TOO SMALL - XXXXX, NECESSARY SIZE = XXXXX

   The storage space reserved by the CALL INPUT statement is not large enough to accommodate the referenced array. The maximum input array size allowed by EBPA is 600. No LOC entry should exceed this value.

2. NO ZERO PART CASE DATA

Columns 71-72 contain a non-zero value. Part case capability is not provided by the program.

Subroutine EQUIL

ITER STOP

Indicates all 20 iterations in equilibrium computations were used. Program continues.

Subroutine GEMTRY

FAILED TO RECOMPUTE THETAW - CASE TERMINATED***

The maximum number of attempts to reduce the current cavity half angle to achieve positive annulus radius and/or cross sectional area has been reached. Control is returned to the executive routine for a new case of data. This problem occurs usually from too large an input value for the base bleed rate.

Subroutine GEOM

DZ TOO LARGE

Projections of computational element along the plate are changed from the ZY to the ZX plane. Execution continues.

Subroutine HBAL

HBAL FAILURE I, HLP, W1(4), HUP, ETU FTL

(Printed values for each variable)

Chemistry could not converge on current temperature for given enthalpy. Program continues with generated value. The value may be out of range for a particular zone but not for the whole mix. If so, nonconvergence could cause case failure.

Subroutine JETPEN

*PENETRATION HEIGHT LARGER THAN 3/4 OF INJECTION SITE DISTANCE.

HITE=XXX.XXXXXX FEET*

Shock disturbance exceeds distance from jet to base. Program proceeds to next case. Lower penetration height or enlarge body length and resubmit case.

Section 8

ENVIRONMENT

This section identifies the hardware and support software required for execution of the External Burning Propulsion Analysis Program.

PROGRAM LANGUAGE

The External Burning program is written primarily in the FORTRAN extended programming language. Less than 2 percent of the program includes the assembler programming language COMPASS.

FORTRAN Compiler

The FORTRAN Extended (FTN) compiler must be used for the EBPA program. This compiler has the capability to optimize program execution speed and to reduce the size of object module.

COMPASS Assembler

The COMPASS Assembler is the symbolic programming language for the Control Data 6000, 7000 and CYBER 170 Series control and peripheral processors.

EXISTENT UTILITIES

Object modules generated by the FORTRAN and COMPASS compilers are loaded, edited and updated by existent utilities.

LOADER

The loader provides editing and loading of object modules generated by the compilers. In addition to normal load functions, the loader provides facilities to create overlay and segmentation load modules.

OPERATING ENVIRONMENTS

The EBPA program has been enabled, with minimal modification of segmentation directives, to operate under the following systems:

COMPUTER	COMPILER	ASSEMBLER	OPERATING SYSTEM
1. CYBER 170/CDC 7600	FTN 4.1+69	COMPASS 3.0-069	NOS 1.4
2. CYBER 174	FTN 4.7+485	COMPASS 3.6-485	NOS 1.3
3. CDC 6600	FTN 4.7+476	COMPASS 3.5-476	NOS/BE 1.3

Appendix
PROPELLANT FORMULATIONS CONTAINED IN PROGRAM DATA BLOCK

Data on a variety of propellants and fuels are stored in data block FRJIB and can be called by user input for the EBPA program. The propellants can be selected from a list which includes bipropellants, momopropellants and solid propellants. Air and hydrogen may also be selected in addition to mixtures of hydrogen and nitrogen at two different temperature levels. The desired propellants can be called by number from the following list:

1. Air

   $N_{79}O_{21}$

   Heat of formation 0.0 cal/g

2. Monomethylhydrazine

   $H_6\ C_1\ N_2$

   Heat of formation 276.0 cal/g

3. Nitrogen tetroxide

   $N_2\ O_4$

   Heat of formation -47.0 cal/g

4. Hydrazine

   $N_2\ H_4$

   Heat of formation 377.0 cal/g

5. Chlorine pentafluoride

   $C\ell\ F_5$

   Heat of formation -464.0 cal/g

6. Pentaborane

   $B_5\ H_9$

   Heat of formation 122.5 cal/g

7. ARP Solid Propellant

   $C_{2.130}\ H_{2.850}\ O_{3.541}\ N_{0.943}\ Pb_{0.008}$

   Heat of formation -566.2 cal/g

8. AGJ Solid Propellant

$C_{2.712}\ H_{4.030}\ O_{3.200}\ Pb_{0.003}$

Heat of formation -632.1 cal/g

9. Aluminized Composite Solid Propellant

$H_{0.0566}\ C_{0.03196}\ N_{0.00249}\ O_{0.00929}\ A\ell_{0.01112}\ C\ell_{0.00213}$

Heat of formation -196.0 cal/g

10. Boronized Composite Solid Propellant

$H_{0.07804}\ B_{0.00924}\ C_{0.04617}\ N_{0.00265}\ O_{0.009636}\ C\ell_{0.002128}$

Heat of formation -216.3 cal/g

11. ARC UpSTAGE JIC Solid Propellant

$H_{0.4799}\ C_{0.1873}\ N_{0.05843}\ O_{0.2208}\ C\ell_{0.05348}$

Heat of formation -424.5 cal/g

12. H_2 at 1500 F

H_2

Heat of formation 2767.6 cal/g

13. H_2/N_2 at 1500 F $X(H_2) = 0.30$

$H_{3.0}\ N_{7.0}$

Heat of formation 286.0 cal/g

14. H_2/N_2 at 1500 F $X(H_2) = 0.667$

$H_{2.0}\ N_{1.0}$

Heat of formation 531.0 cal/g

15. H_2/N_2 at 1000 F $X(H_2) = 0.667$

$H_{2.0}\ N_{1.0}$

Heat of formation 338.7 cal/g

16. UpSTAGE EB Gas Generator Solid Propellant

$C_{2.599}\ H_{3.867}\ O_{3.391}\ N_{0.758}$

Heat of formation -741.1 cal/g

17. Triethylaluminum

$H_{6.0}\ C_{15.0}\ A\ell_{1.0}$

Heat of formation -291.7 cal/g

18. Aluminum borohydride

$A\ell\ B_{3.0}\ H_{12.0}$

Heat of formation -300.0 cal/g

19. ARC Solid Propellant Arcadene 168

$C_{.7969}\ H_{3.1561}\ N_{.4576}\ Cl_{.4511}\ Al_{1.2973}$

Heat of formation	-362.62	cal/g